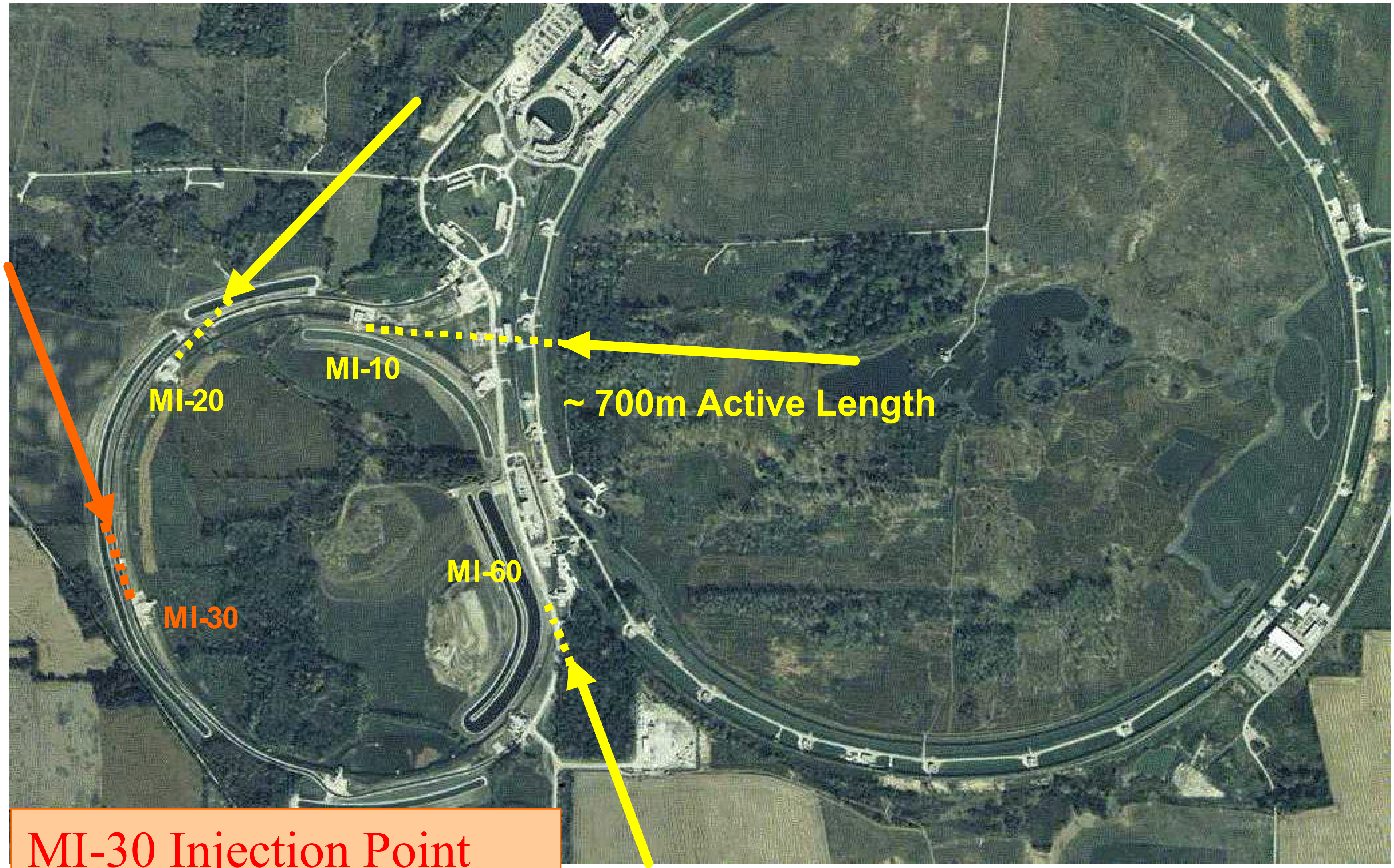
A Multi-Mission 8 GeV Superconducting Injector Linac

G. William Foster

Fermilab Long-Range Planning / Proton Driver Presentations
Oct 09, 2003

8 GeV Superconducting Linac
Possible Sitings for MI Injection



MI-30 Injection Point
Chosen for Design Study

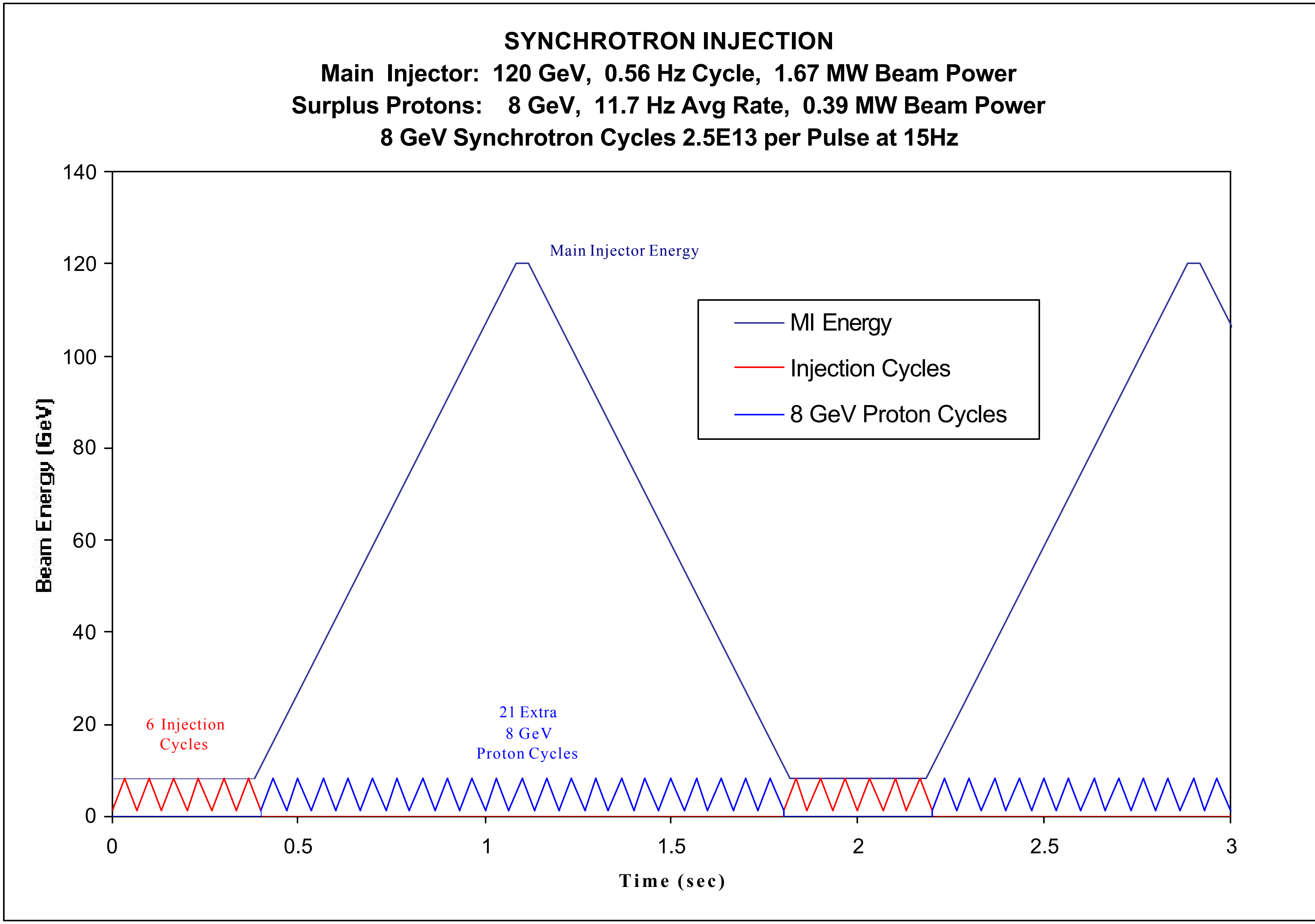
8 GeV Superconducting Linac

- New idea incorporating concepts from both SNS and TESLA.
  - Copy SNS Linac design up to 1.3 GeV
  - Use "TESLA" Cryomodules from 1.3 - 8 GeV
  - H^- Injection at 8 GeV in Main Injector

==> "Super-Beams" in Fermilab Main Injector:

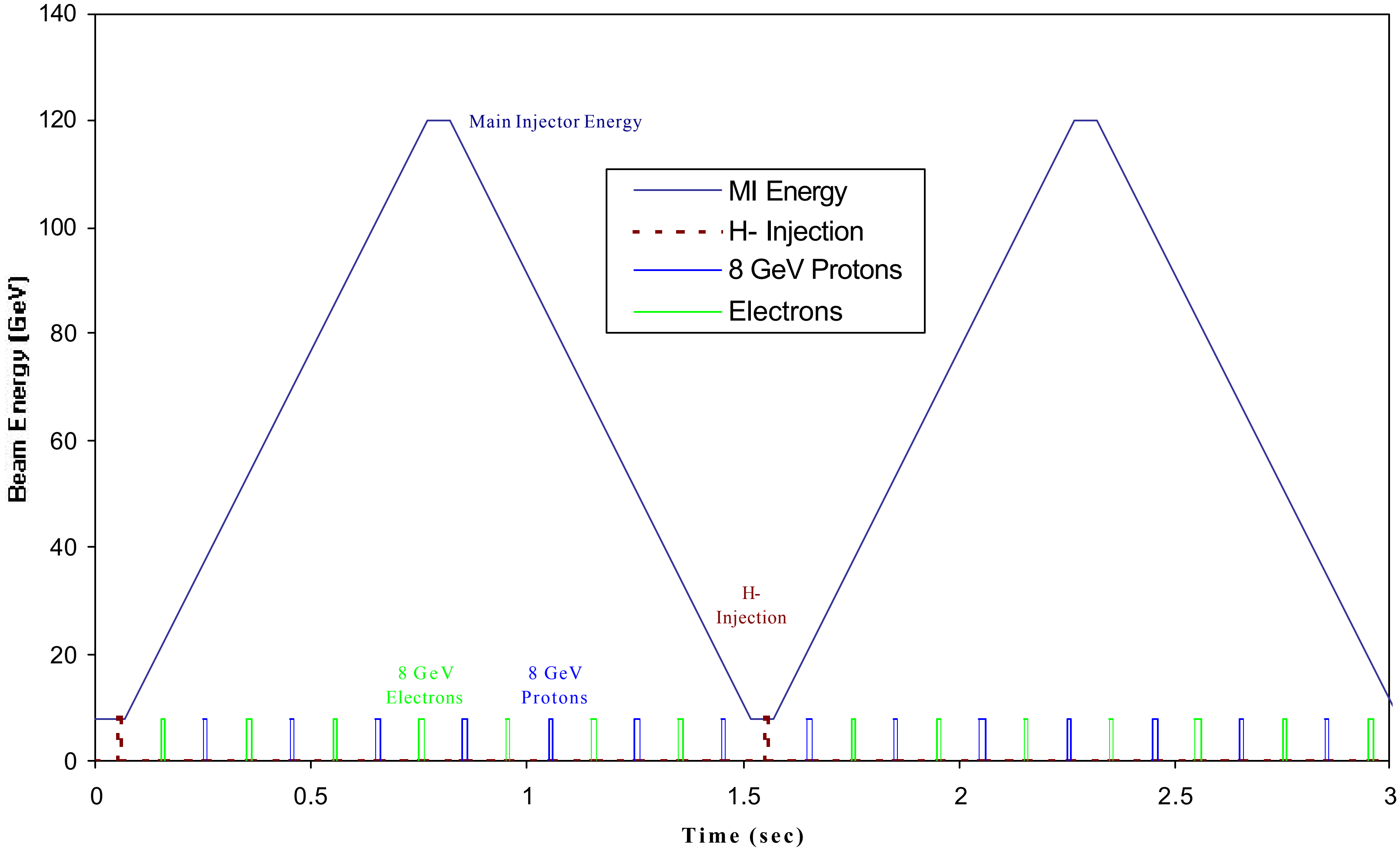
- 2 MW Beam power at BOTH 8 GeV and 120 GeV
- Small emittances ==> Small losses in Main Injector
- Minimum (1.5 sec) cycle time
- MI Beam Power Independent of Beam Energy
  ==> *(flexible neutrino program)*

120 GeV Main Injector Cycle with 8 GeV Synchrotron

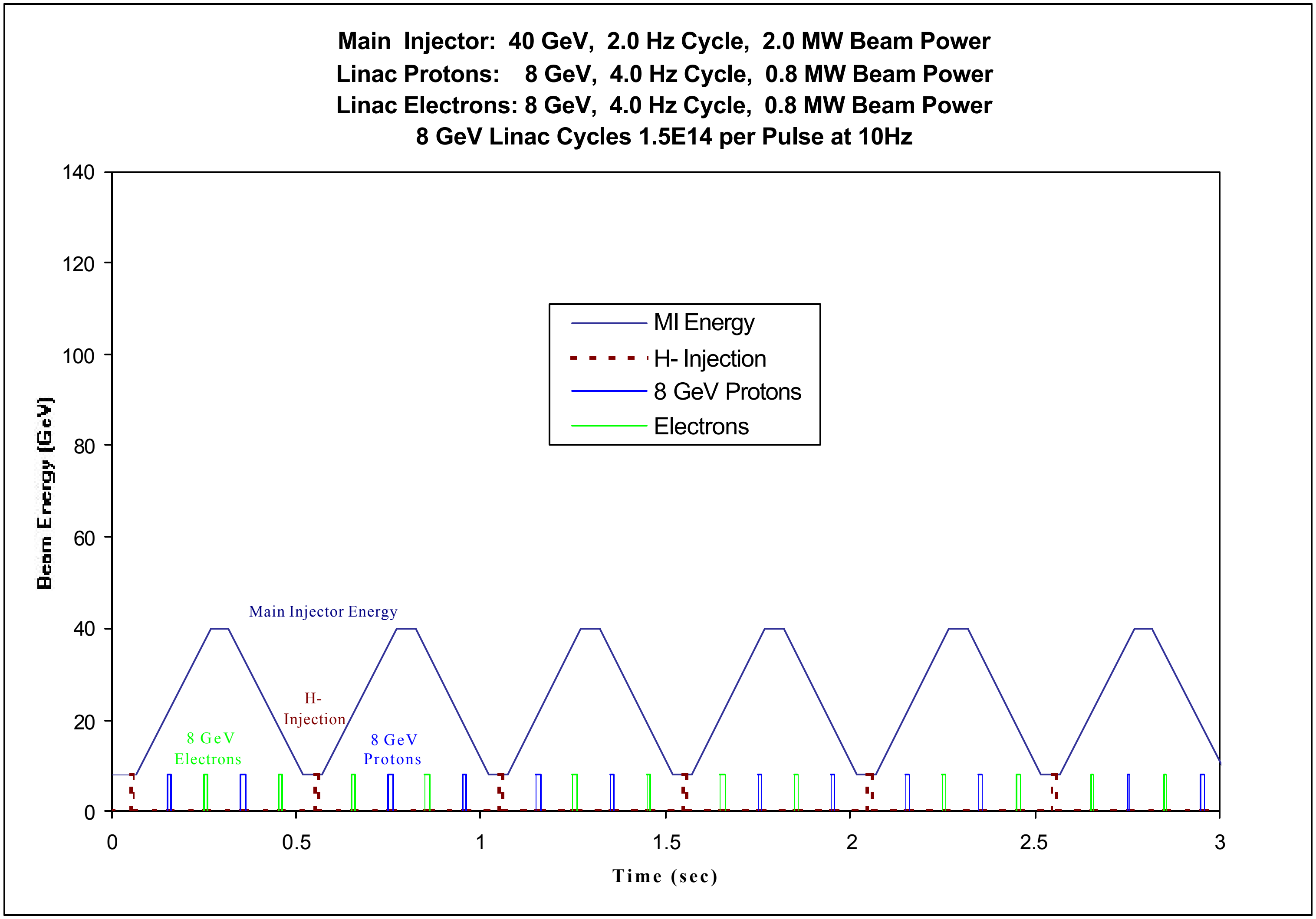


120 GeV Main Injector Cycle with 8 GeV Linac, e- and P

Main Injector: 120 GeV, 0.67 Hz Cycle, 2.0 MW Beam Power
Linac Protons: 8 GeV, 4.67 Hz Cycle, 0.93 MW Beam Power
Linac Electrons: 8 GeV, 4.67 Hz Cycle, 0.93 MW Beam Power
8 GeV Linac Cycles 1.5E14 per Pulse at 10Hz

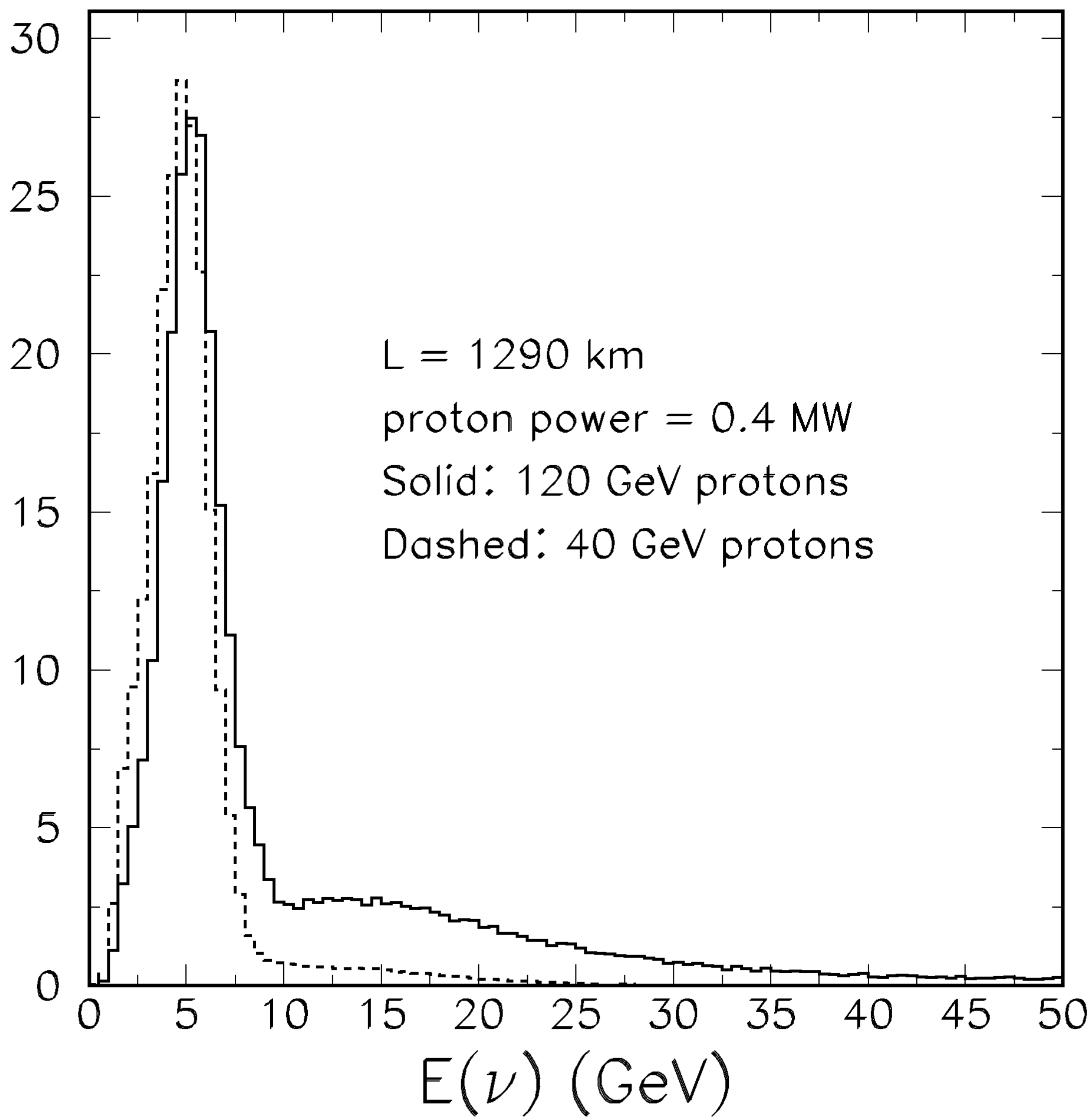


8 GeV Linac Allows Reduced MI Beam Energy without Compromising Beam Power



MI cycles to 40 GeV at 2Hz, retains 2 MW MI beam power

Running at Reduced Proton Energy Produces a Cleaner Neutrino Spectrum



- Running at 40 GeV reduces tail at higher neutrino energies.
- Same number of events for same beam power.

(Plot courtesy Fritz & Debbie)

Injector Linac Parameters

- Beam Energy = **8 GeV**
  - Same as existing Booster
  - Anywhere from 5~15 GeV would be OK
- Beam Pulse: **25mA x 1msec**
  - Same as SNS (==> Beam Physics Studied)
  - Fills Main Injector at 5x Design Intensity (2 MW)
- Rep Rate: **10 Hz** (MI uses only 0.6 Hz)
  - Same as TESLA (==> Multi-Beam Klystrons)
  - 2 MW stand-alone beam power for other uses

Superconducting Linac
Parameters

Project Info:
tdserver1.fnal.gov/project/8gevlinac

8 GeV LINAC

Energy	GeV	8	
Particle Type	H- Ions, Protons, or Electrons		
Rep. Rate	Hz	10	
Active Length	m	671	
Beam Current	mA	25	
Pulse Length	msec	1	
Beam Intensity	P / pulse	1.5E+14	(can be H-, P, or e-)
	P/hour	5.4E+18	
Linac Beam Power	MW avg.	2	
	MW peak	200	

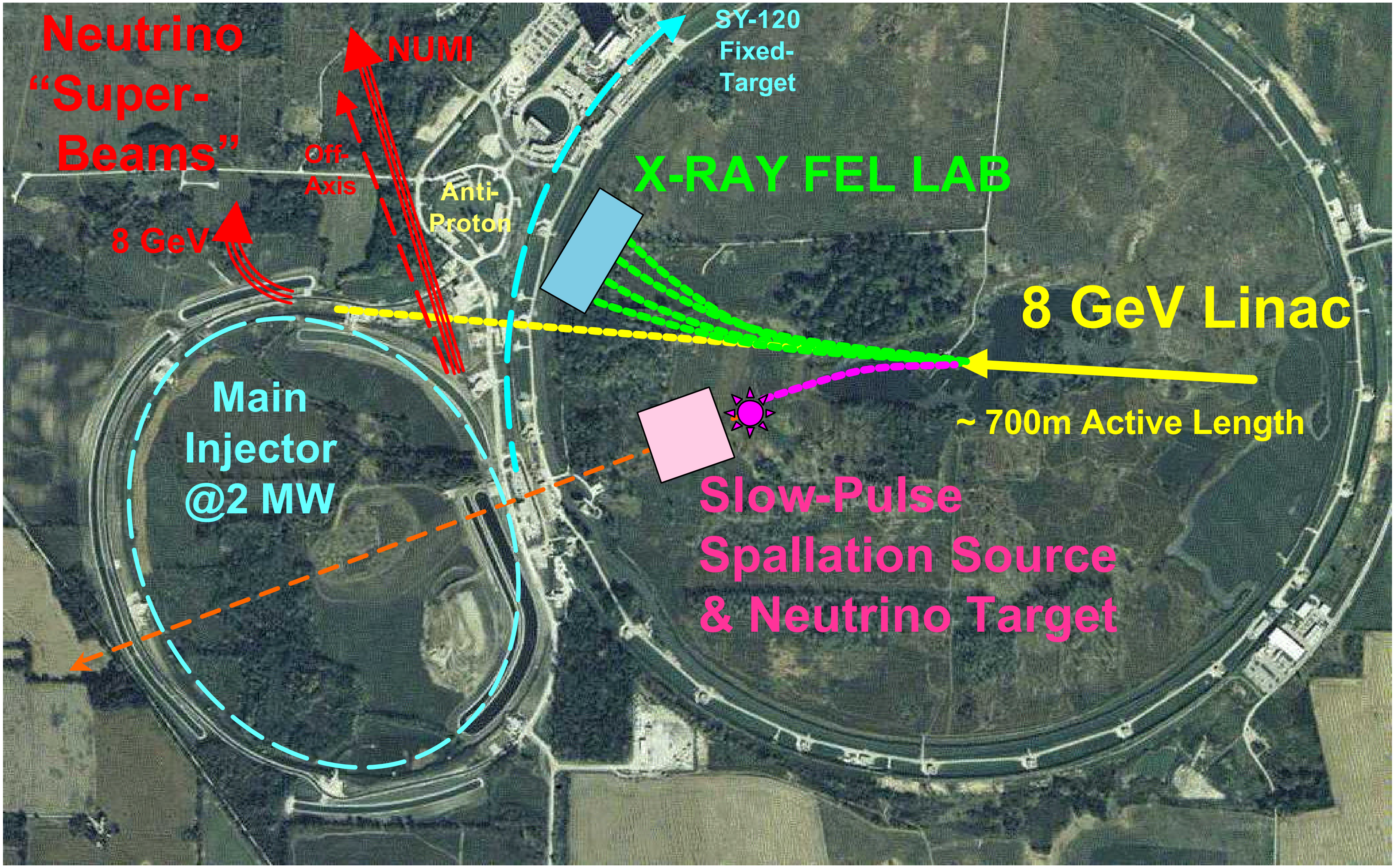
MAIN INJECTOR WITH 8 GeV LINAC

MI Beam Energy	GeV	120	
MI Beam Power	MW	2.0	
MI Cycle Time	sec	1.5	filling time = 1msec
MI Protons/cycle		1.5E+14	5x design
MI Protons/hr	P / hr	3.6E+17	
H-minus Injection	turns	90	SNS = 1060 turns
MI Beam Current	mA	2250	

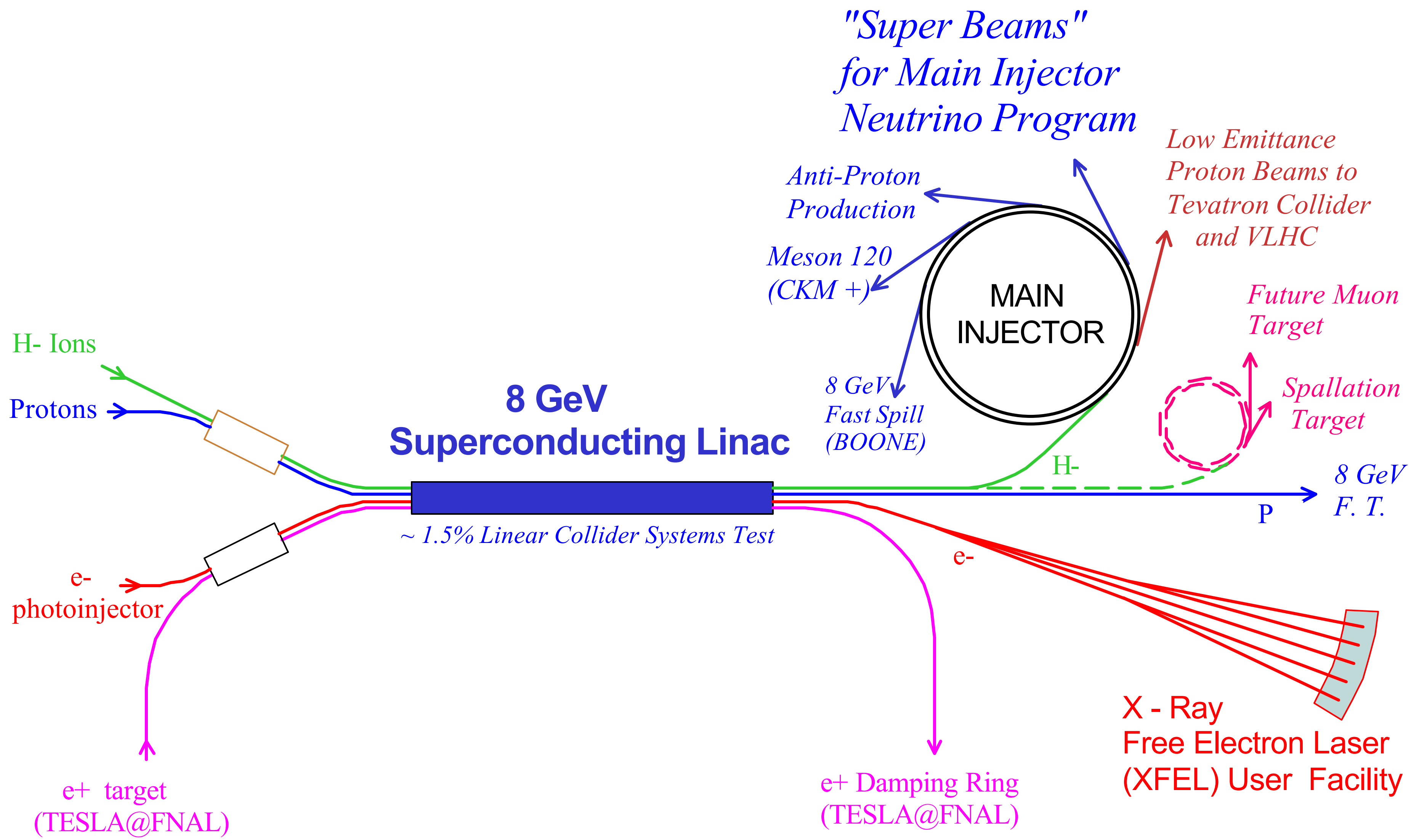
8 GeV S.C. Linac Can Accelerate electrons, positrons, H- and protons

- The linac pulses at 10 Hz, but the MI only uses 0.6 Hz.
- The last 7 GeV of the linac can accelerate e+- or P
  – Requires fast ferrite phase shifters (complete SNS R&D)
- Other possible missions for unused linac cycles:
  – 8 GeV electrons can drive XFEL
  – 8 GeV neutrinos, Spallation Neutron or Muon sources, etc.
  – 8 GeV Linac could eventually become e+ pre-accelerator for TESLA @FNAL

8 GeV Superconducting Linac
With X-Ray FEL and 8 GeV Spallation & Neutrino Source



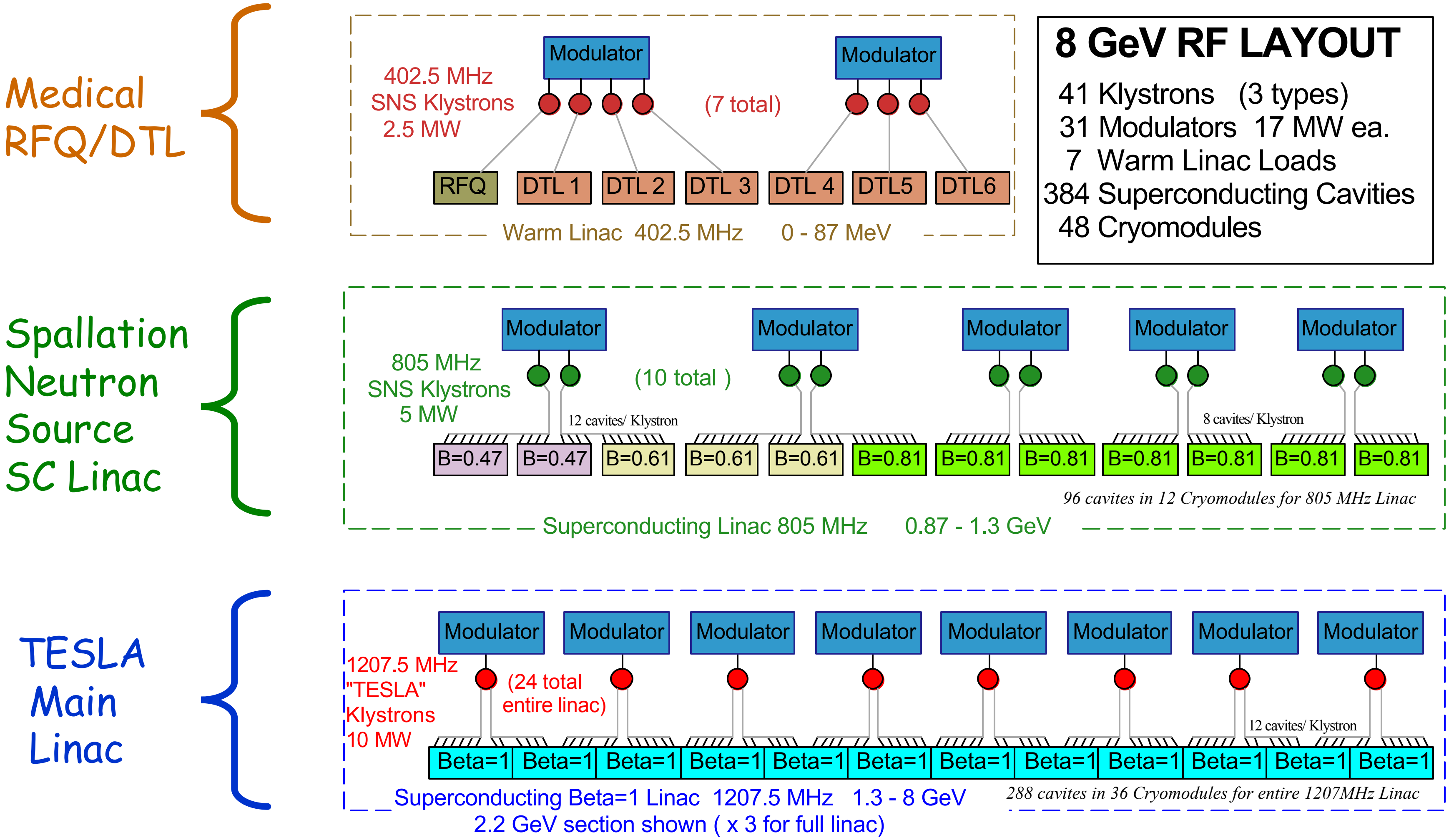
Multi-Mission 8 GeV Injector Linac



Benefits of 8 GeV Injector Linac

- Benefits to neutrino and Fixed-Target program
  - solves proton economics problem: > 5E18 Protons/hr at 8 GeV
  - operate MI with small emittances, high currents, and low losses
- Benefits to Linear Collider R&D
  - 1.5% scale demonstration of TESLA economics
  - Evades the Linear Collider R & D funding cap
  - Simplifies the Linear Collider technology choice
  - Establishes stronger US position in LC technology
- Benefits to Muon Collider / Neutrino Factory R&D
  - Establishes cost basis for P-driver and muon acceleration
- Benefits to VLHC: small emittances, high Luminosity
  - ~4x lower beam current reduces stored energy in beam
  - Stage 1: reduces instabilities, allows small beam pipes & magnets
  - Stage 2: injection at final synchrotron-damped emittances

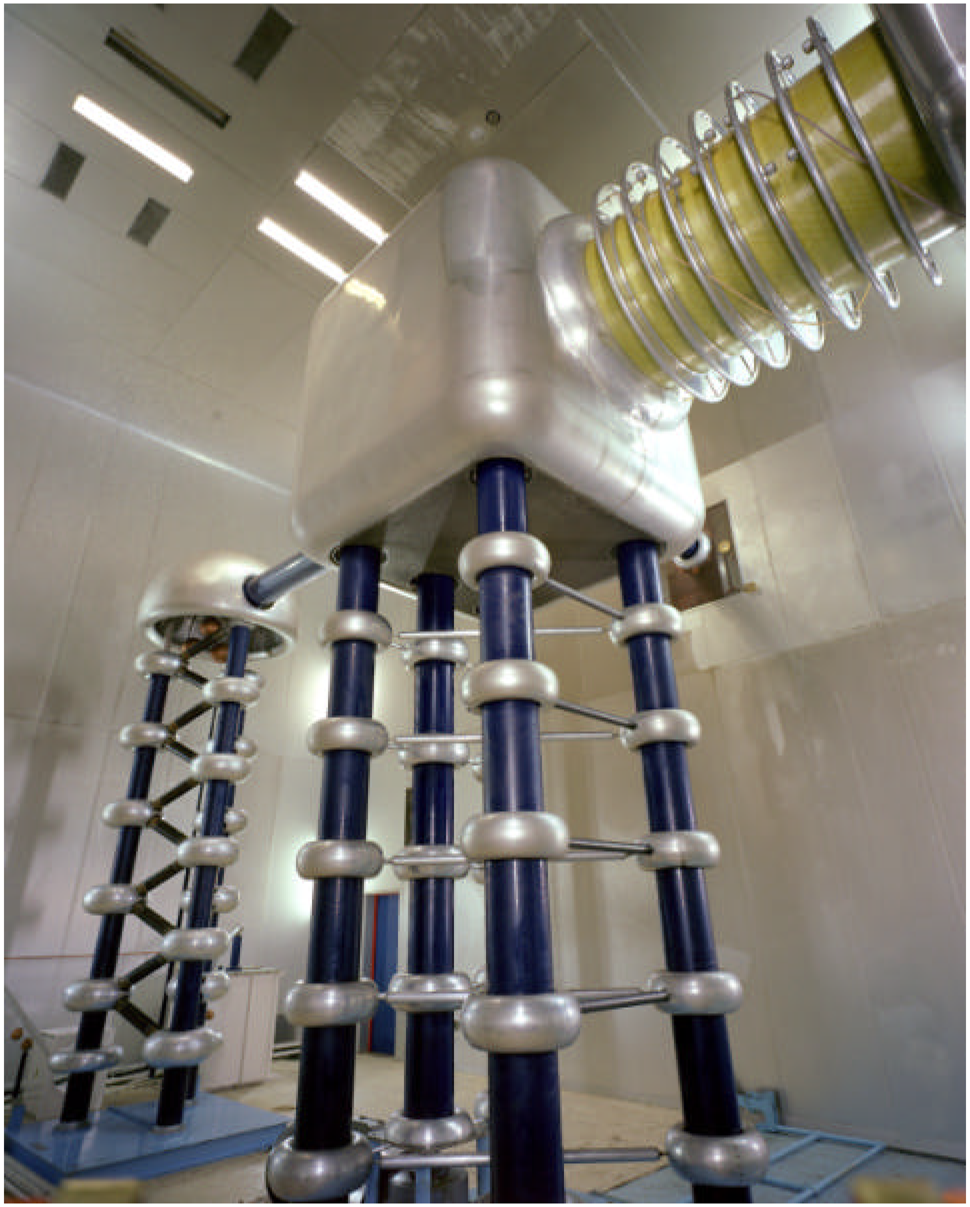
8 GeV Superconducting Linac
Conceptual Layout



8 GeV RF LAYOUT

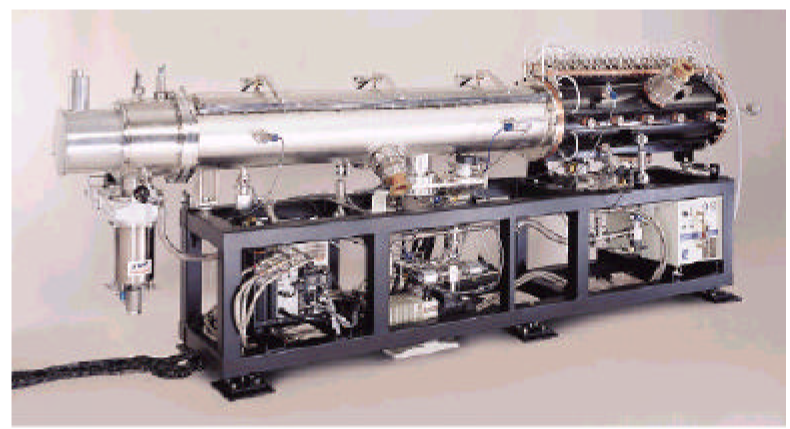
41 Klystrons (3 types)
31 Modulators 17 MW ea.
7 Warm Linac Loads
384 Superconducting Cavities
48 Cryomodules

Proton Source Linac Front End



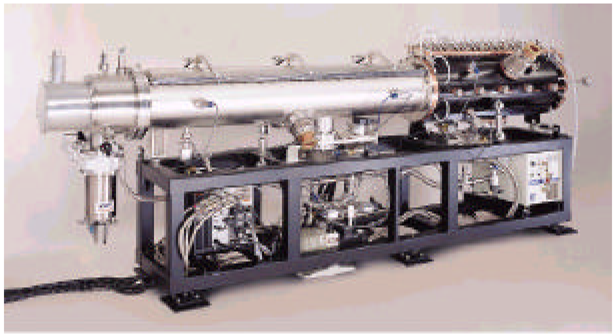
- Original FNAL Cockroft-Walton

MODERN REPLACEMENT

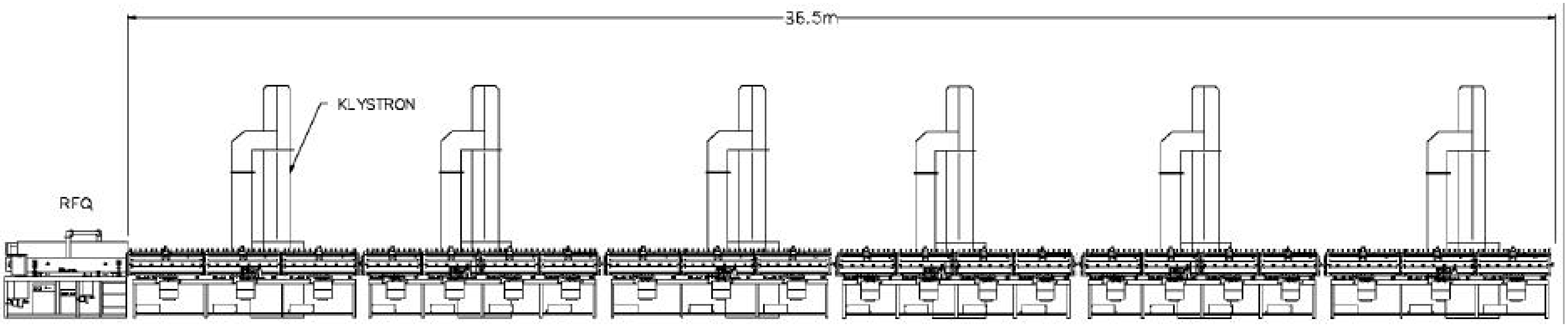


Hitachi / AccSys PL-7 RFQ with one DTL tank

Hitachi / AccSys Source/RFQ/DTL



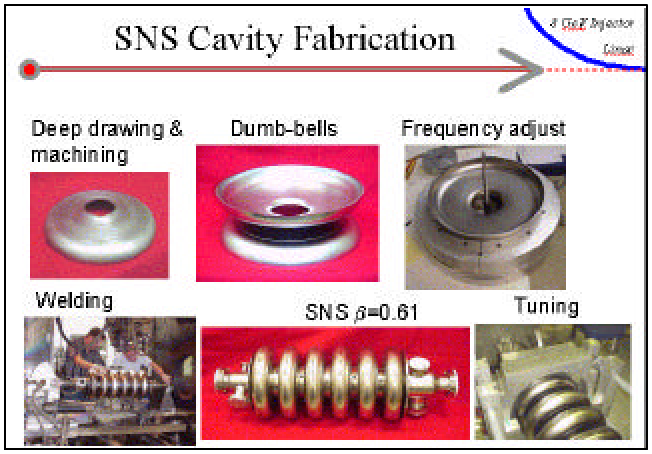
- AccSys PL-7 RFQ with one DTL tank



- Appears to have shorter length and lower price than cloning the SNS Linac, *for 10 Hz operation*

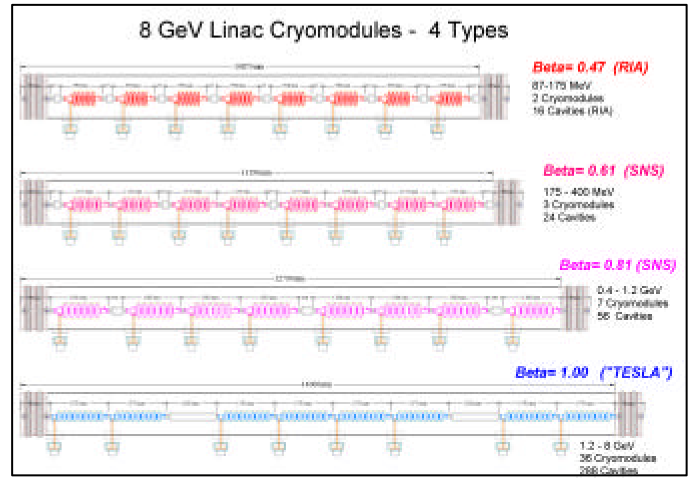
D. Young's work...

8 GeV Superconducting Linac
TECHNICAL SUBSYSTEM DESIGNS *EXIST* AND *WORK*

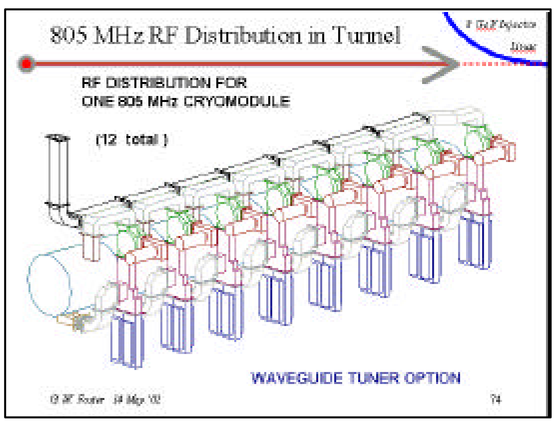


SNS Cavites

FNAL/TTF Modulators

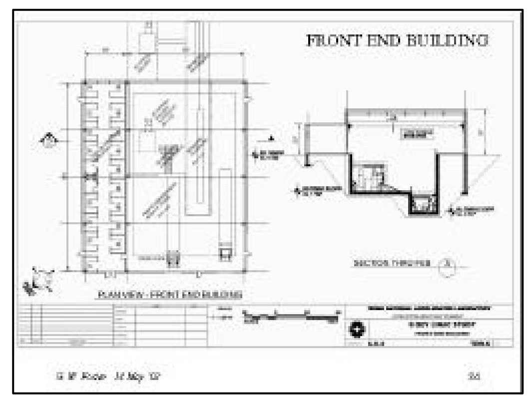


"TTF Style" Cryomodules

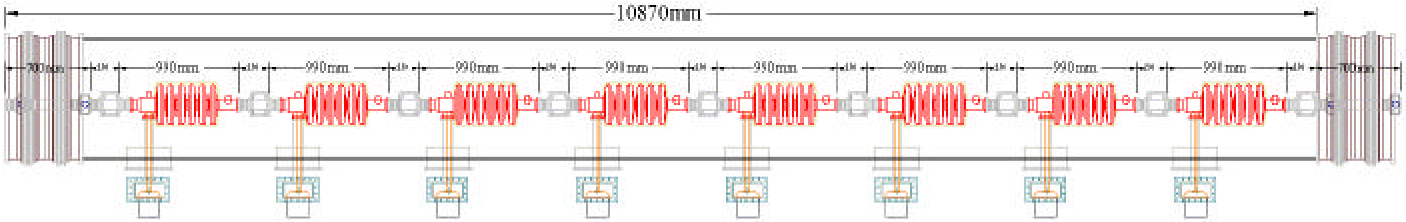


RF Distribution

Civil Const. Based on FMI

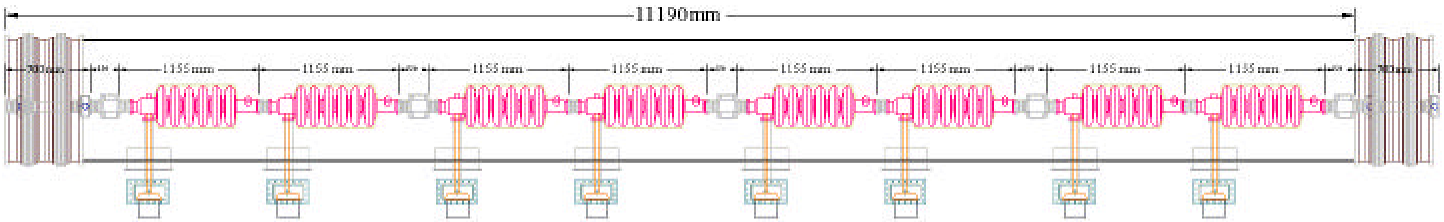


8 GeV Linac Cryomodules - 4 Types



Beta= 0.47 (RIA)

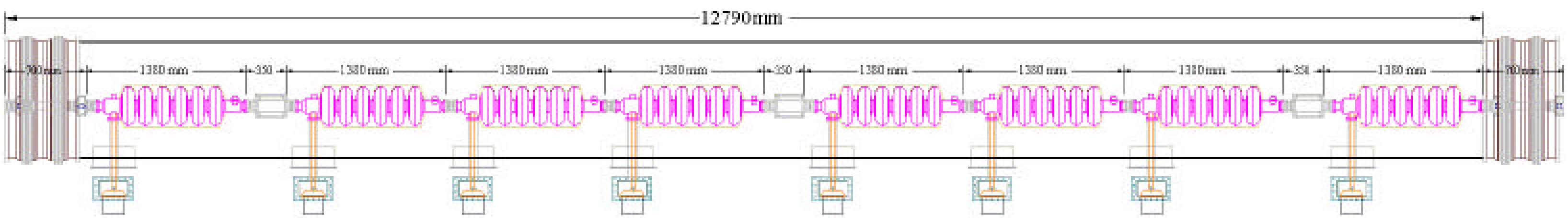
87-175 MeV
2 Cryomodules
16 Cavities (RIA)



Beta= 0.61 (SNS)

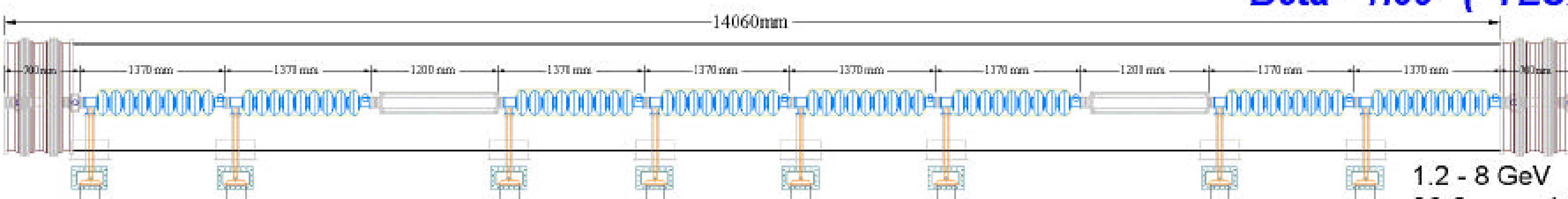
175 - 400 MeV
3 Cryomodules
24 Cavities

Beta= 0.81 (SNS)



0.4 - 1.2 GeV
7 Cryomodules
56 Cavities

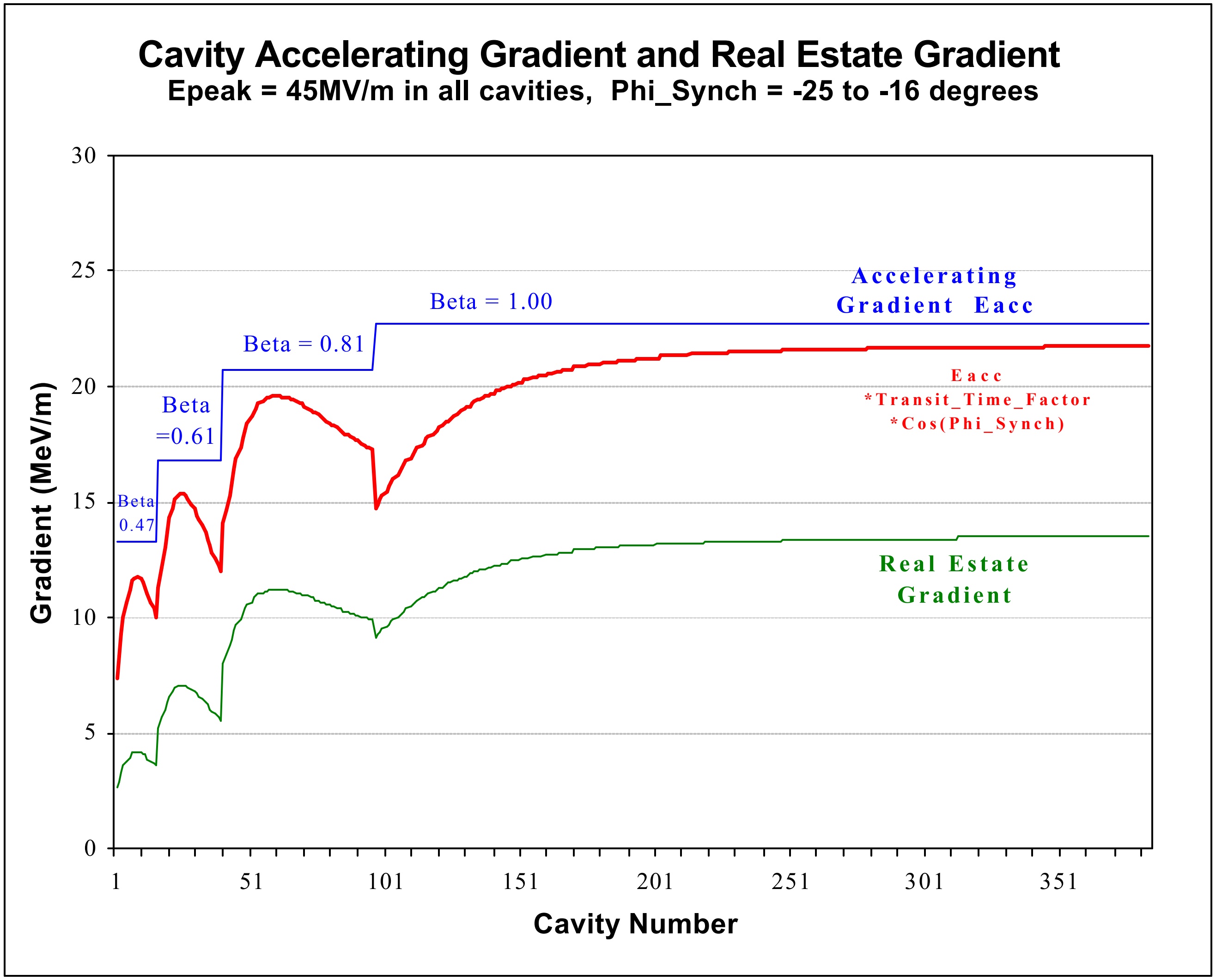
Beta= 1.00 ("TESLA")



1.2 - 8 GeV
36 Cryomodules
288 Cavities

9 Cell Beta=1 Cavities, 1207.5 MHz

Superconducting Cavity Gradients

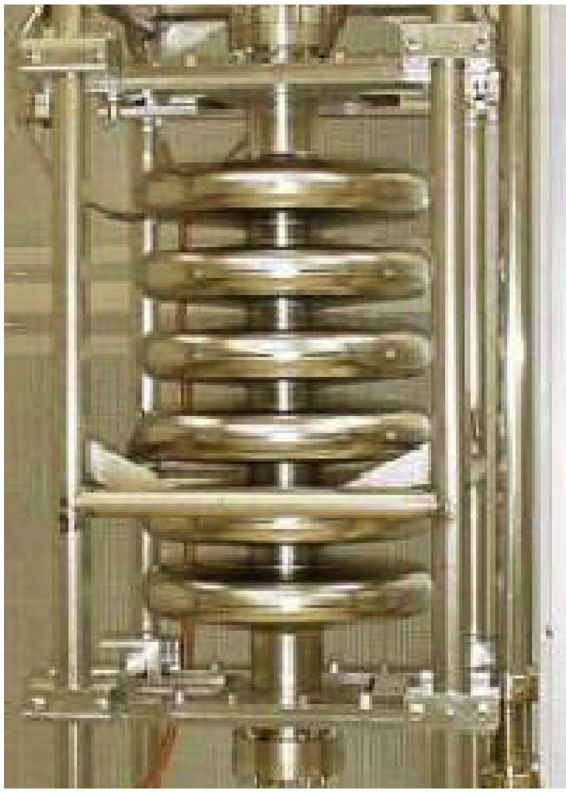


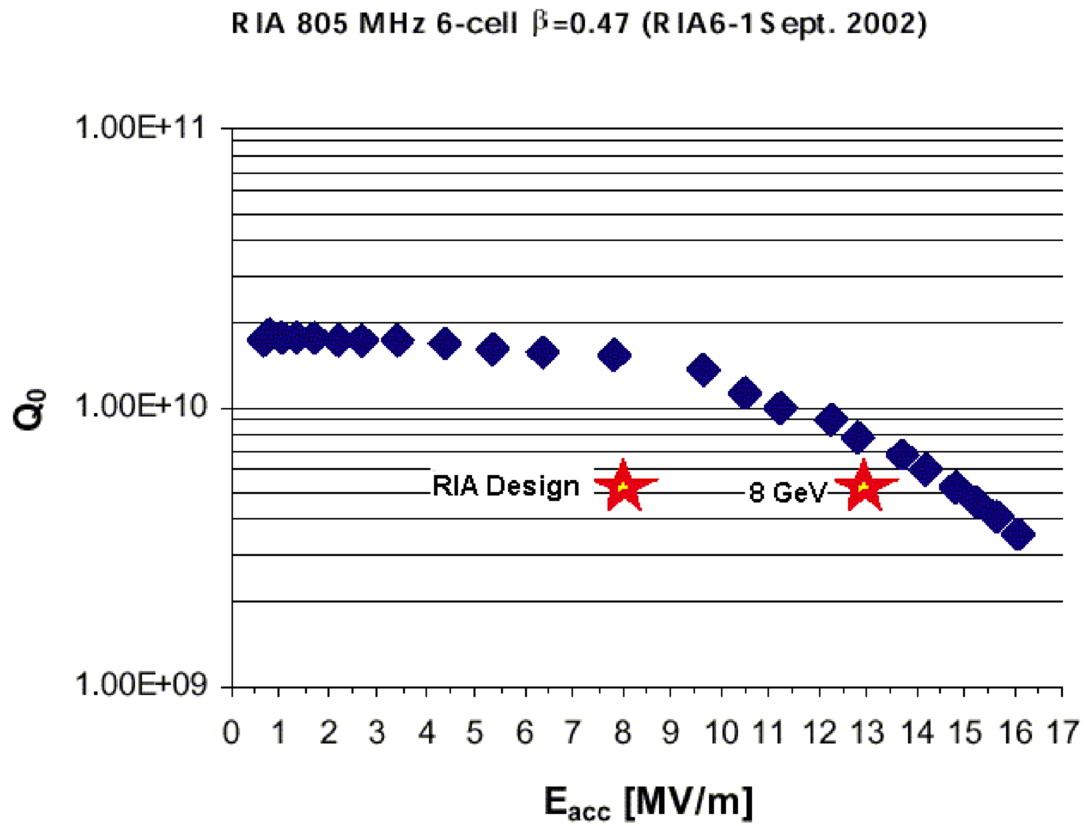
8 GeV design assumes *peak* field in cavities of 45 MV/m.

SNS:
37.5 MV/m
TESLA(500):
47 MV/m
TESLA(800):
~70 MV/m

New results: Beta=0.47 Cavity Tests

MSU/JLAB/INFN for RIA





- Beta=0.47 cavites now exist and exceed specs

SNS Cavity Costs

- We have graciously been given access to SNS actual costs for ~110 completed SCRF RF cavities, tanks, tuners, couplers, etc. including final chemistry and assembly labor.

  (Thanks to N. Holtkamp, E. Daly, Katherine Wilson)
- The 8 GeV Linac needs 416 cavity assemblies ==> $35M for 8 GeV Linac
- This assumes:
  - no quantity discount or rebate for existing tooling
  - that 1.2 GHz 9-cell cavities are the same price as 805 MHz 6-cell SNS cavities of same length

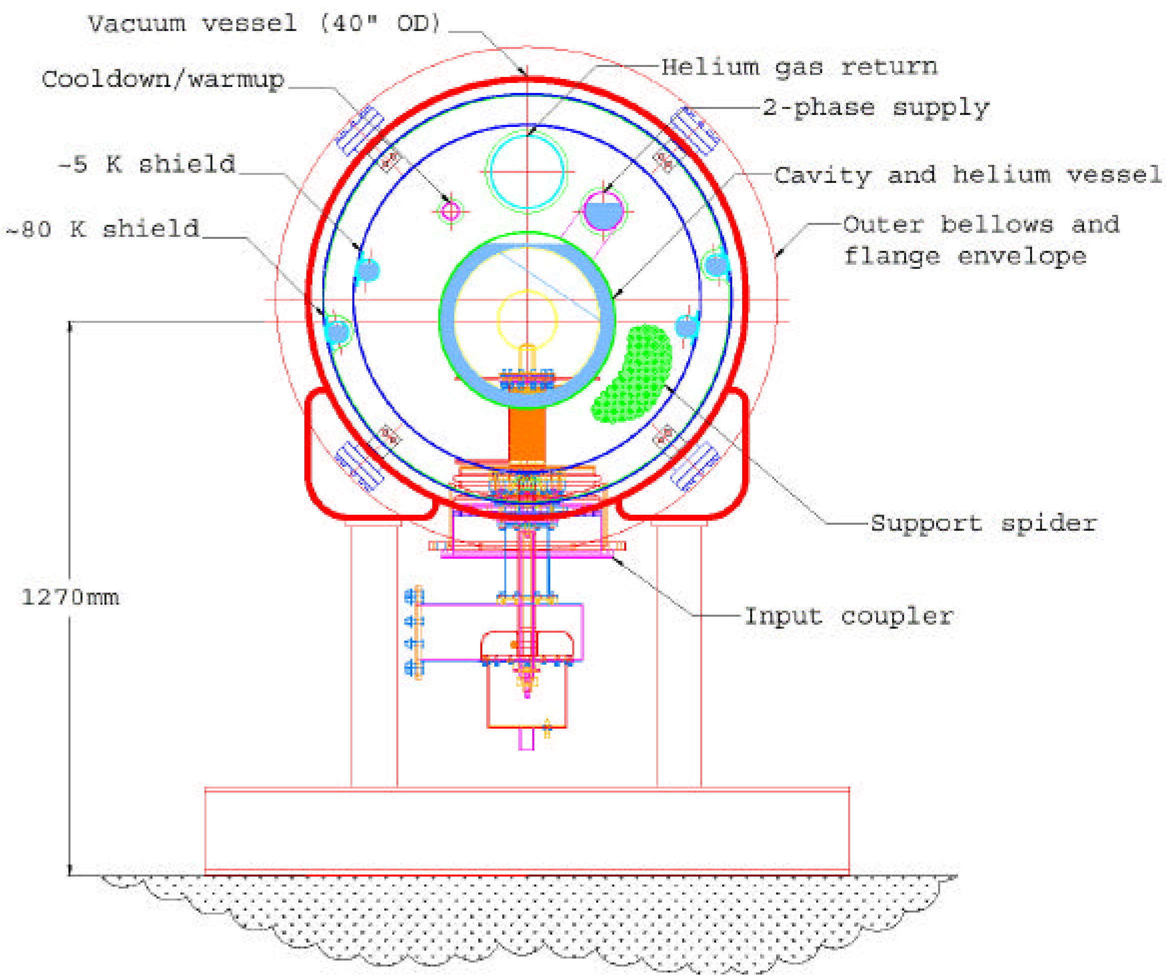
8 GeV Cryomodule Costs

- Costs for SNS cavity assemblies and RF power couplers integrated into TESLA-style cryomodules were estimated by T. Nicol (TD)
  - Tom is the project manager for US LHC cryostats
  - USLHC requires ~270m of cryostats, 8 GeV ~ 650m
- Final Cost including cavities, cryostats, RF couplers, EDIA & labor, no contingency:
  - 52 Cryomodules @ $1093k ea. = $57M

… this is the biggest single cost component

TESLA-Style Cryomodules for 8 GeV

(T. Nicol)



- Design conceptually similar to TESLA
- No warm-cold beam pipe transitions
- No need for large cold gas return pipe
- Cryostat diameter ~ same as LHC
- RF Couplers are KEK/SNS design, conductively cooled for 10 Hz. *(R. Rabehl)*

RF - Klystrons

- 402.5 MHz / 2.5 MW (7 total)
- 805 MHz / 5.0 MW (10 total)

SNS Actual

- 1207.5 MHz / 10 MW (36 total)

TESLA Design

Scaled by ~ 7% from 1.3GHz

Modulators for Klystrons

- Biggest single component in RF costs
- Pfeffer, Wolff, & Co. (FNAL BD) have been making TESLA spec modulators for years
- FNAL Bouncer design in service at TTF since 1994

Modulator Circuit

- IGBT / Capacitor Discharge circuit
- Bouncer to maintain flat top
- Redundant Switch with Ignitron Crowbar
- Pulse Transformer 10kV to 130 kV (typ.)

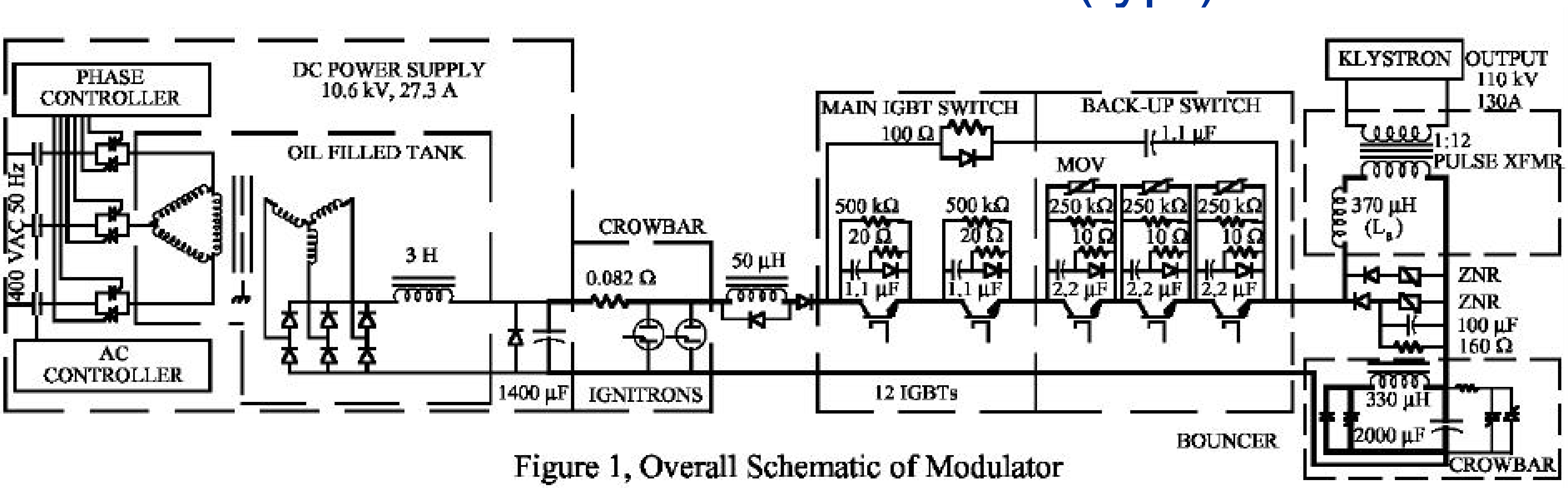


Figure 1, Overall Schematic of Modulator

H. Pfeffer, D. Wolff, & sons.

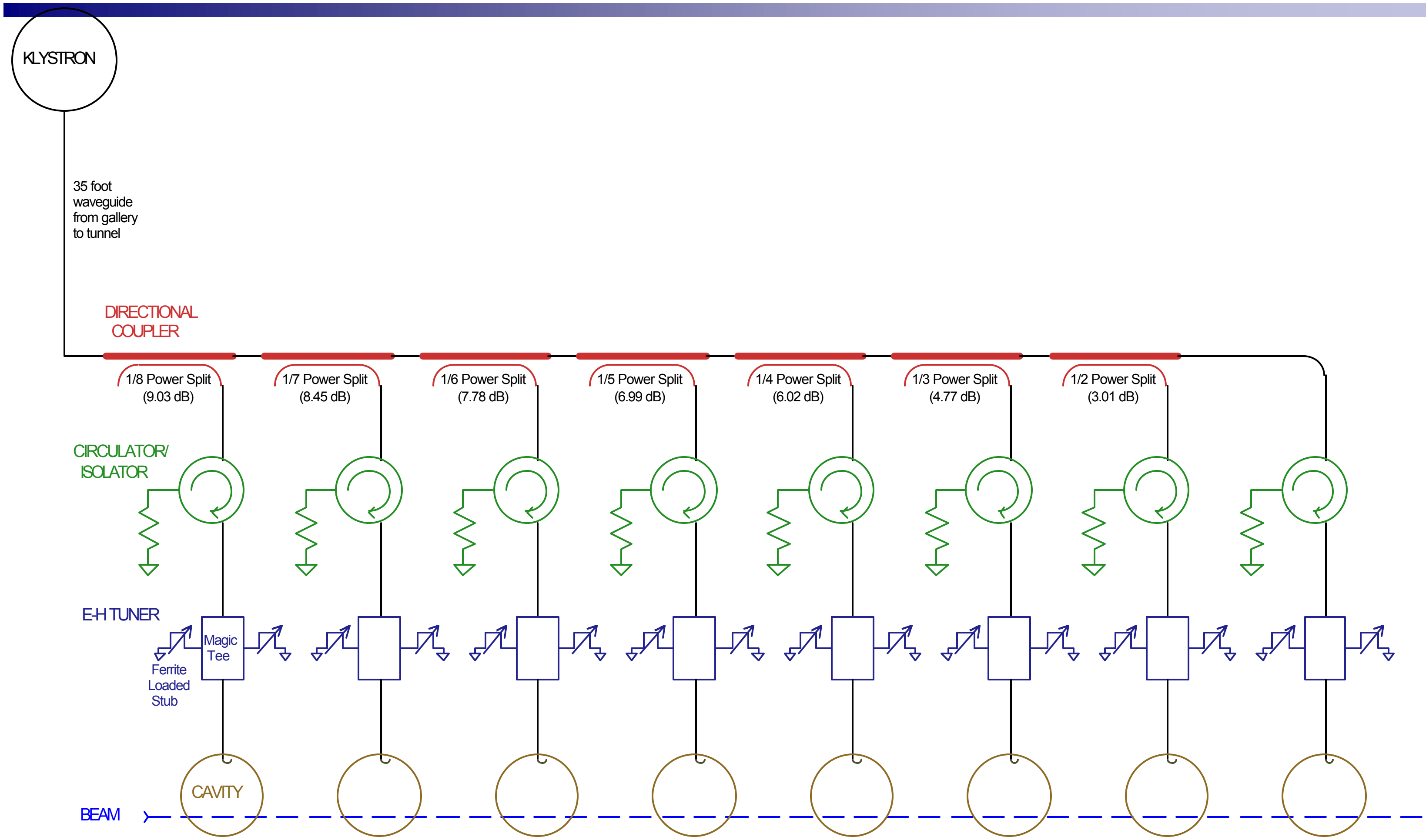
Fast Ferrite Phase Shifter R&D

- Provides fast, flexible drive to individual cavites of a proton linac, when one is using a TESLA-style RF fanout. *(1 klystron feeds 36 cavities)*
- Also needed if Linac alternates between e and P.
- This R&D was started by SNS but dropped due to lack of time. They went to one-klystron-per-cavity which cost them a lot of money (~$20M / GeV).

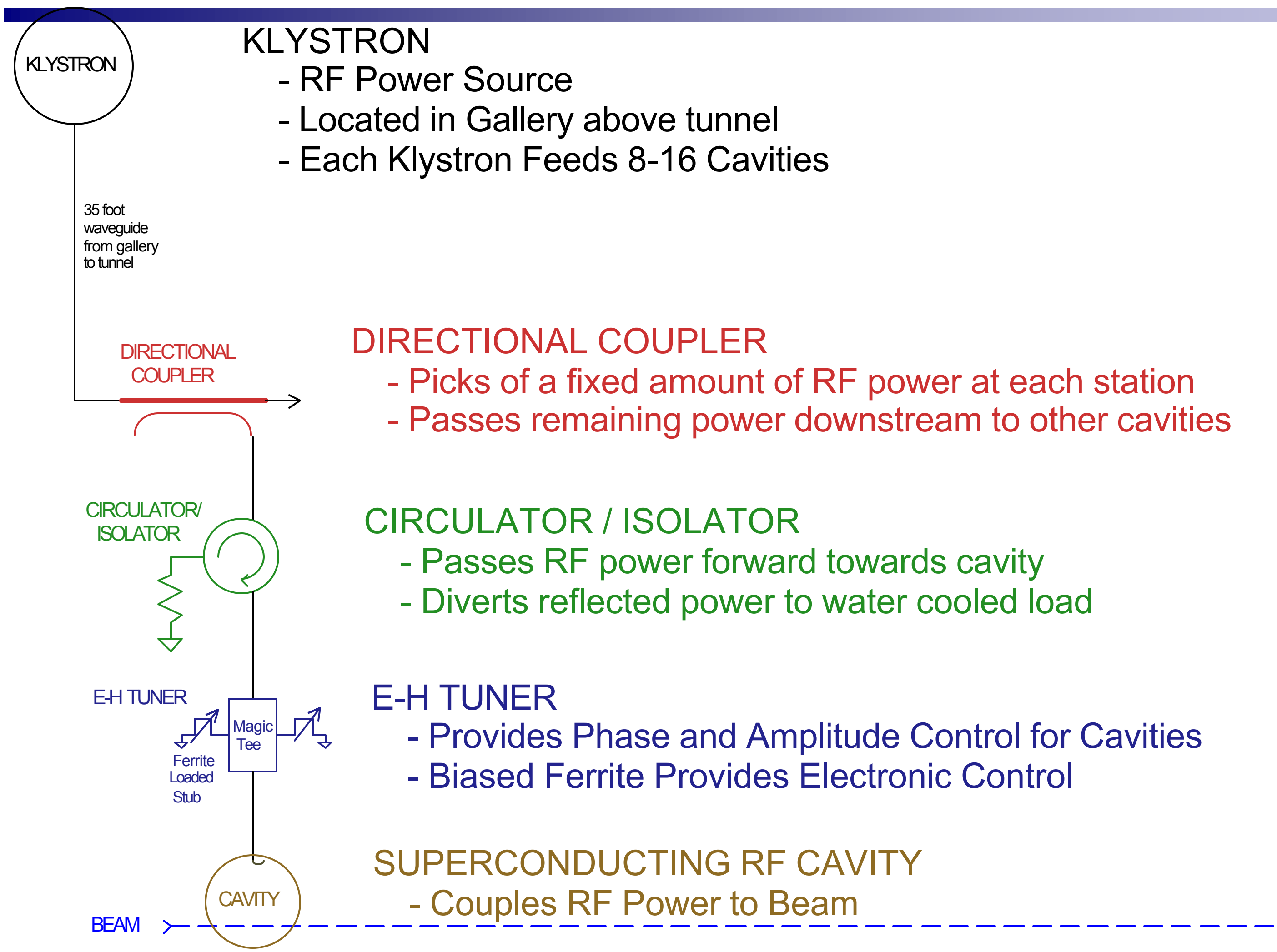
Making this technology work is key to the financial feasibility of the 8 GeV Linac.

RF Fan-out for 8 GeV Linac

A. Moretti, D. Wildman



RF Fanout at Each Cavity



KLYSTRON
- RF Power Source
- Located in Gallery above tunnel
- Each Klystron Feeds 8-16 Cavities

DIRECTIONAL COUPLER
- Picks of a fixed amount of RF power at each station
- Passes remaining power downstream to other cavities

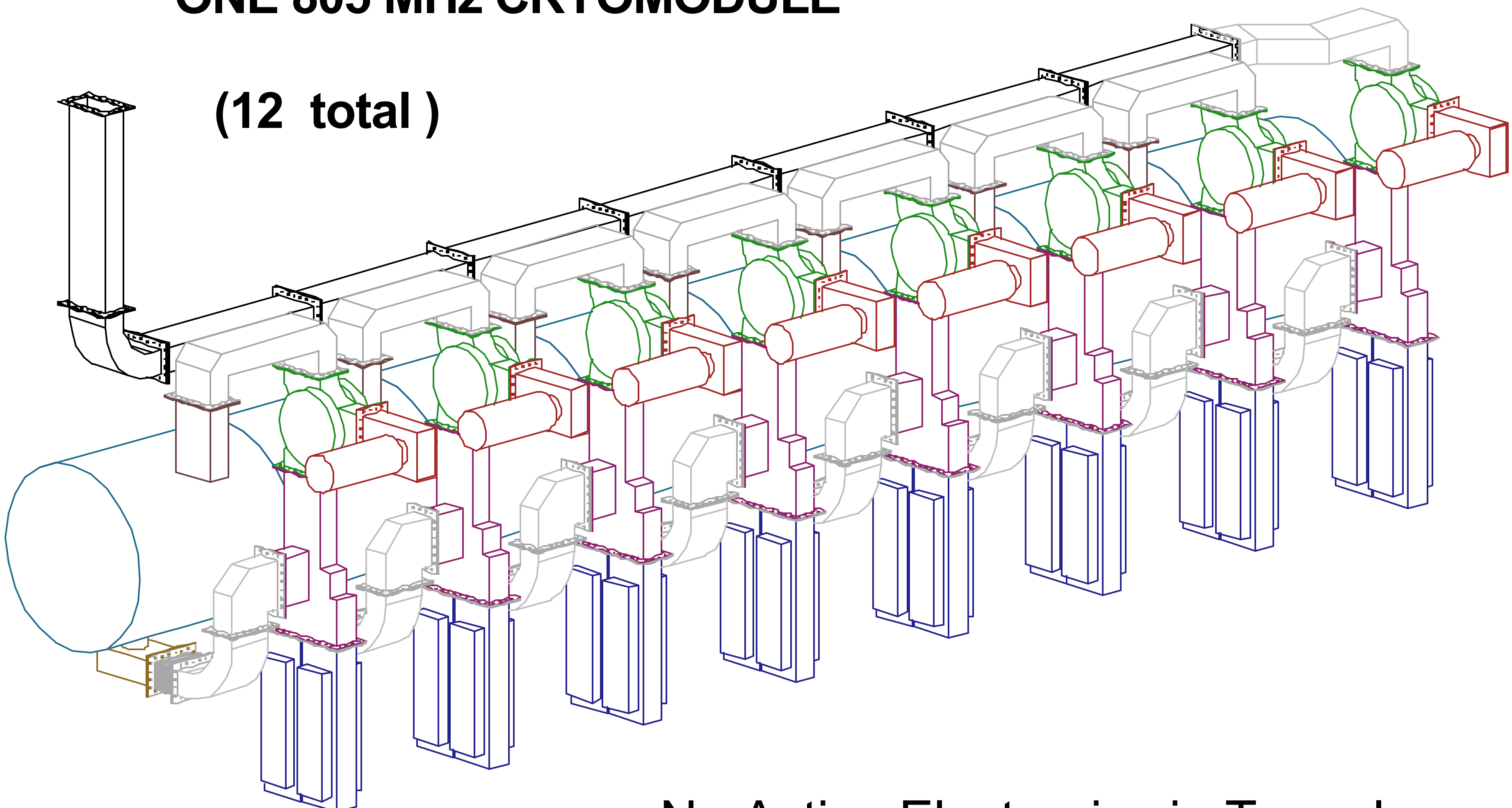
CIRCULATOR / ISOLATOR
- Passes RF power forward towards cavity
- Diverts reflected power to water cooled load

E-H TUNER
- Provides Phase and Amplitude Control for Cavities
- Biased Ferrite Provides Electronic Control

SUPERCONDUCTING RF CAVITY
- Couples RF Power to Beam

RF DISTRIBUTION FOR ONE 805 MHz CRYOMODULE

(12 total)

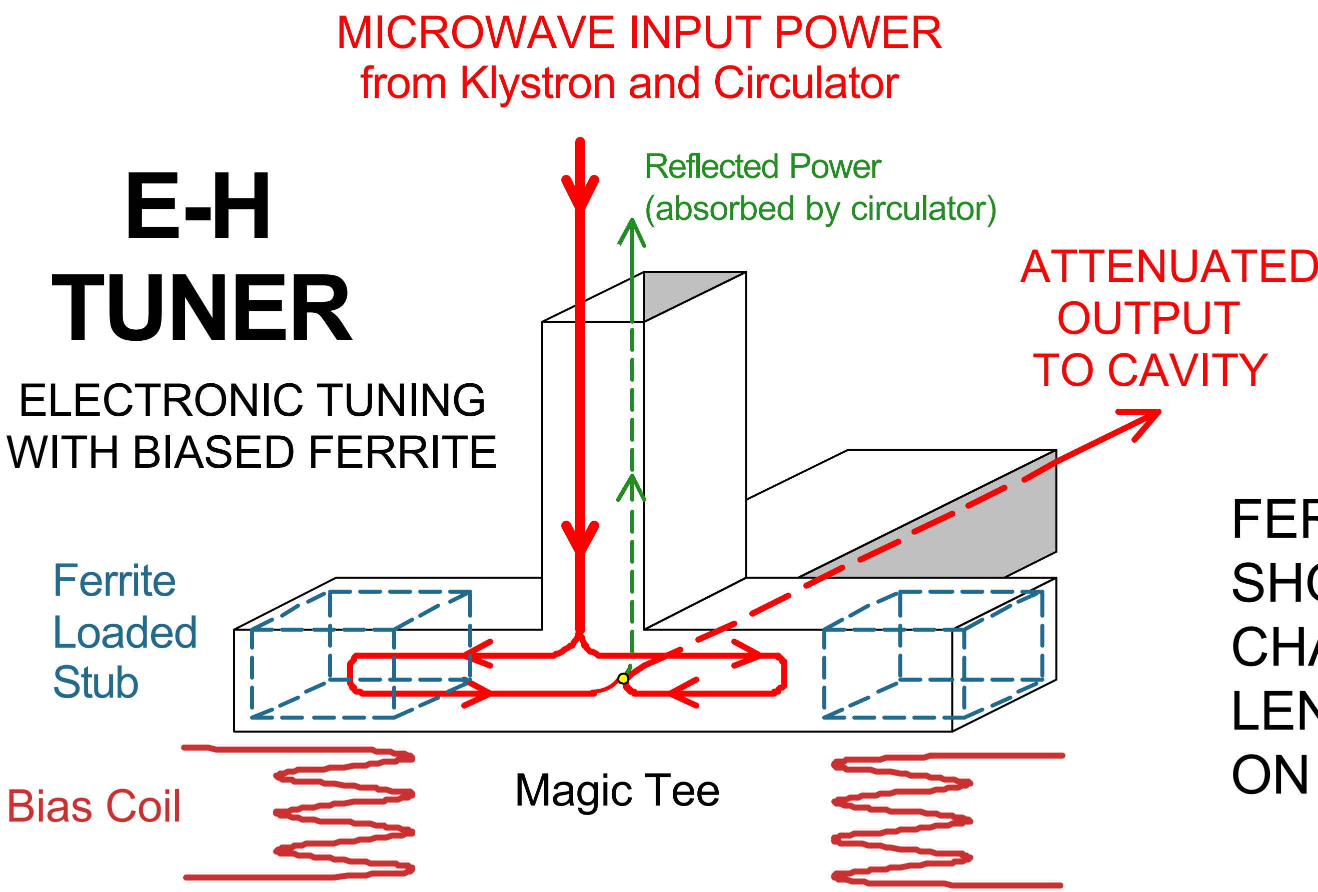


No Active Electronics in Tunnel – only Ferrite & Bias Coils.

ELECTRONICALLY ADJUSTABLE E-H TUNER

E-H TUNER

ELECTRONIC TUNING WITH BIASED FERRITE

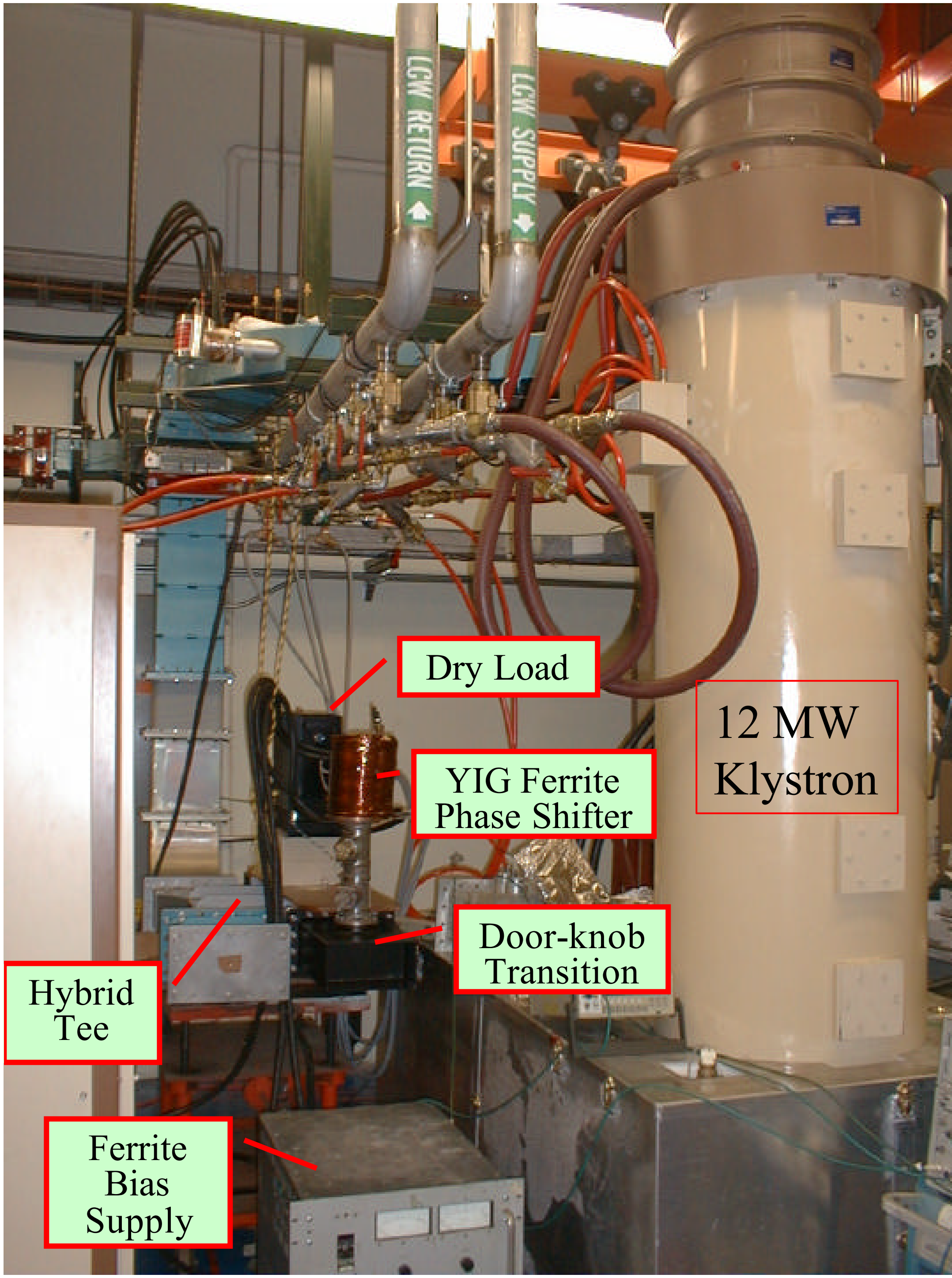


Attractive Price Quote from AFT

(<< Klystron)

FERRITE LOADED SHORTED STUBS CHANGE ELECTRICAL LENGTH DEPENDING ON DC MAGNETIC BIAS.

TWO COILS PROVIDE INDEPENDENT ***PHASE AND AMPLITUDE*** CONTROL OF CAVITIES



Ferrite Phase Shifter High-Power Test Stand

A. Moretti, D. Wildman, N. Solyak, Y. Terechkine

- 805 MHz Klystron
- 12 MW x 100usec

  (need: 0.5 MW x 1 msec)

<u>First goal:</u>

See if existing YIG tuner functions at 500kW. ***(yes!)***

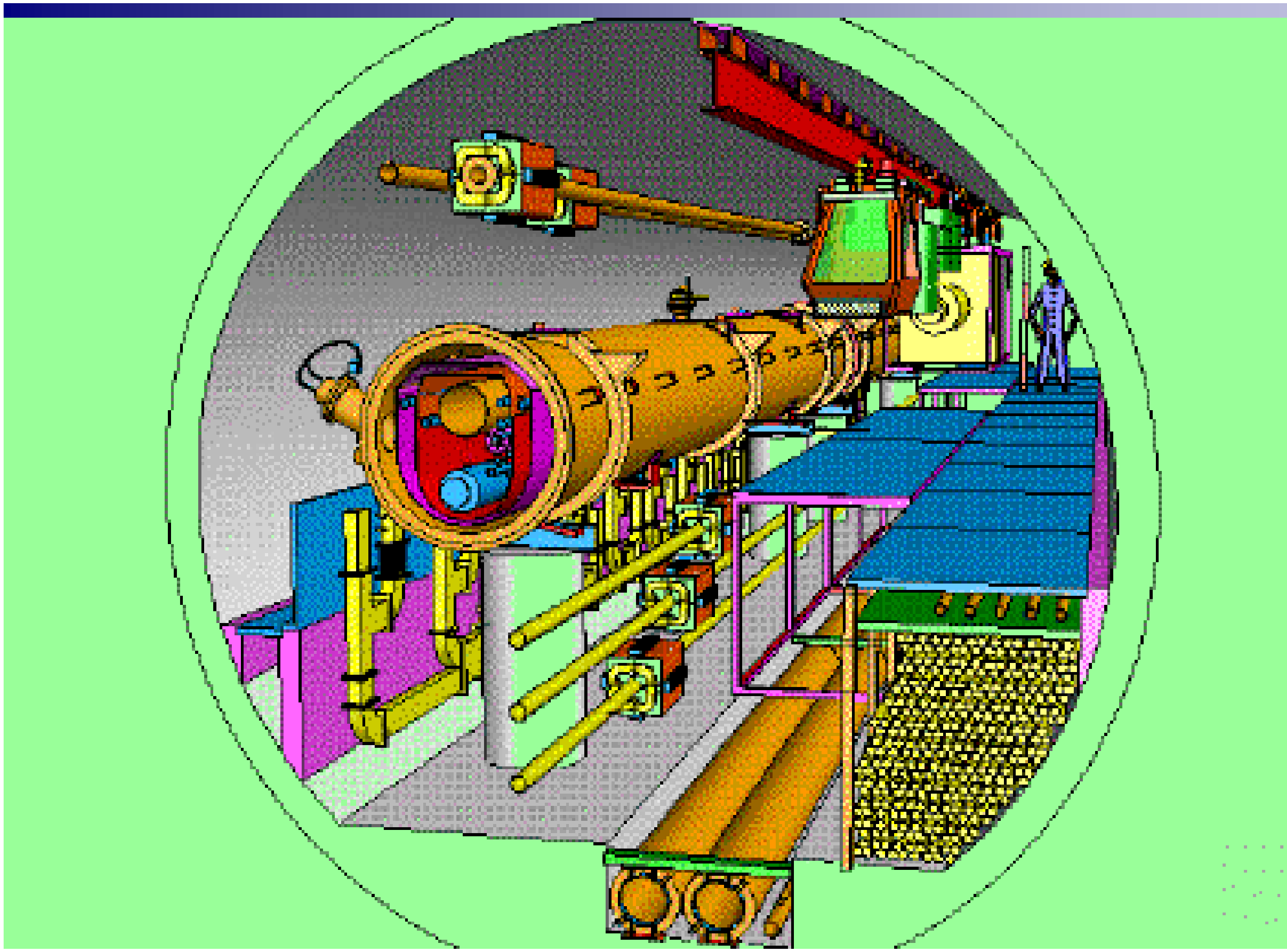
<u>Ultimate Goal:</u>

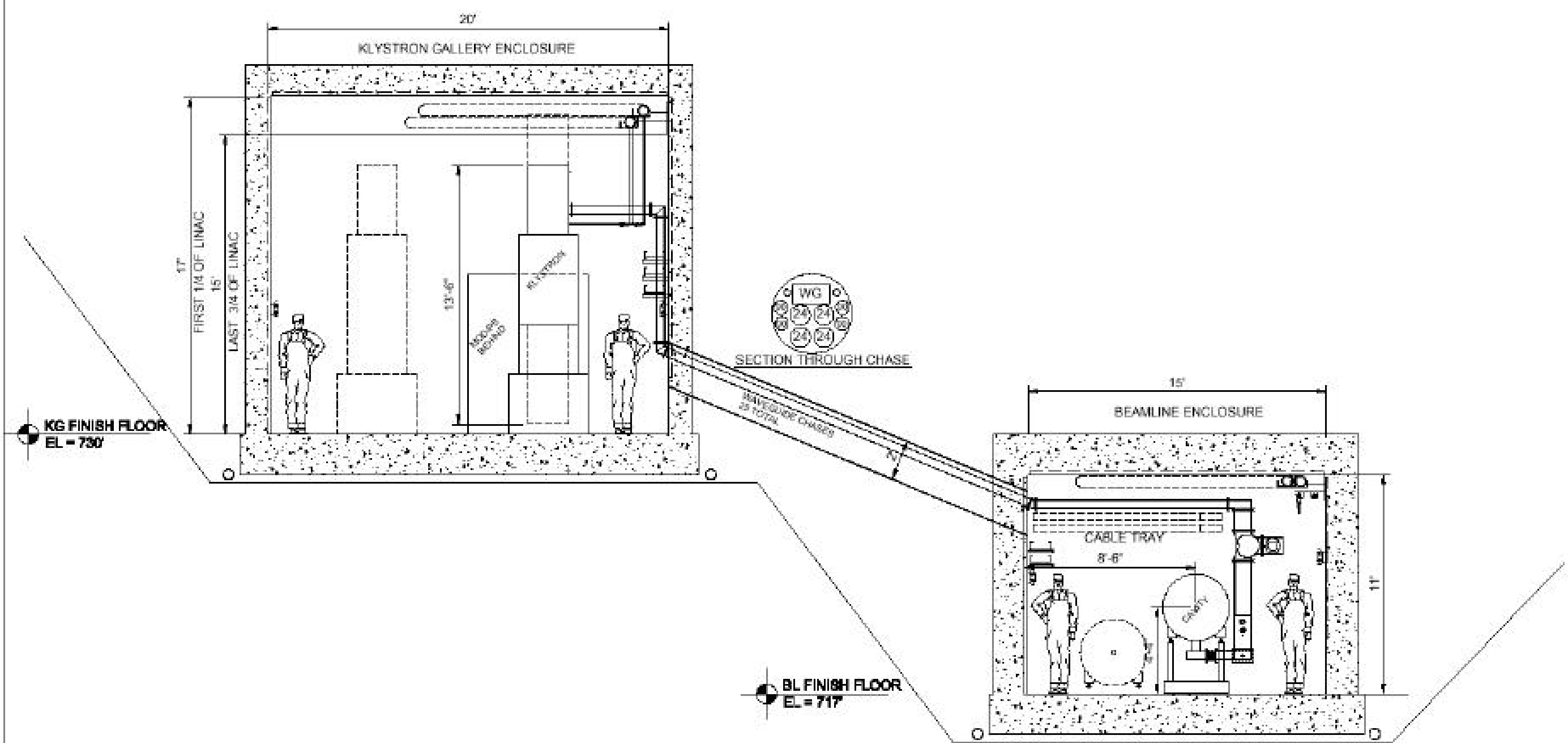
0.2 dB loss for

360 deg. phase shift

in 100~500usec.

TESLA Tunnel & Klystrons





TYPICAL SECTION THROUGH LINAC

SHOWING 805 MHz KLYSTRON AND CAVITY

SCALE: 1" = 5'-0"

SCALE 5 0 5 10 FEET

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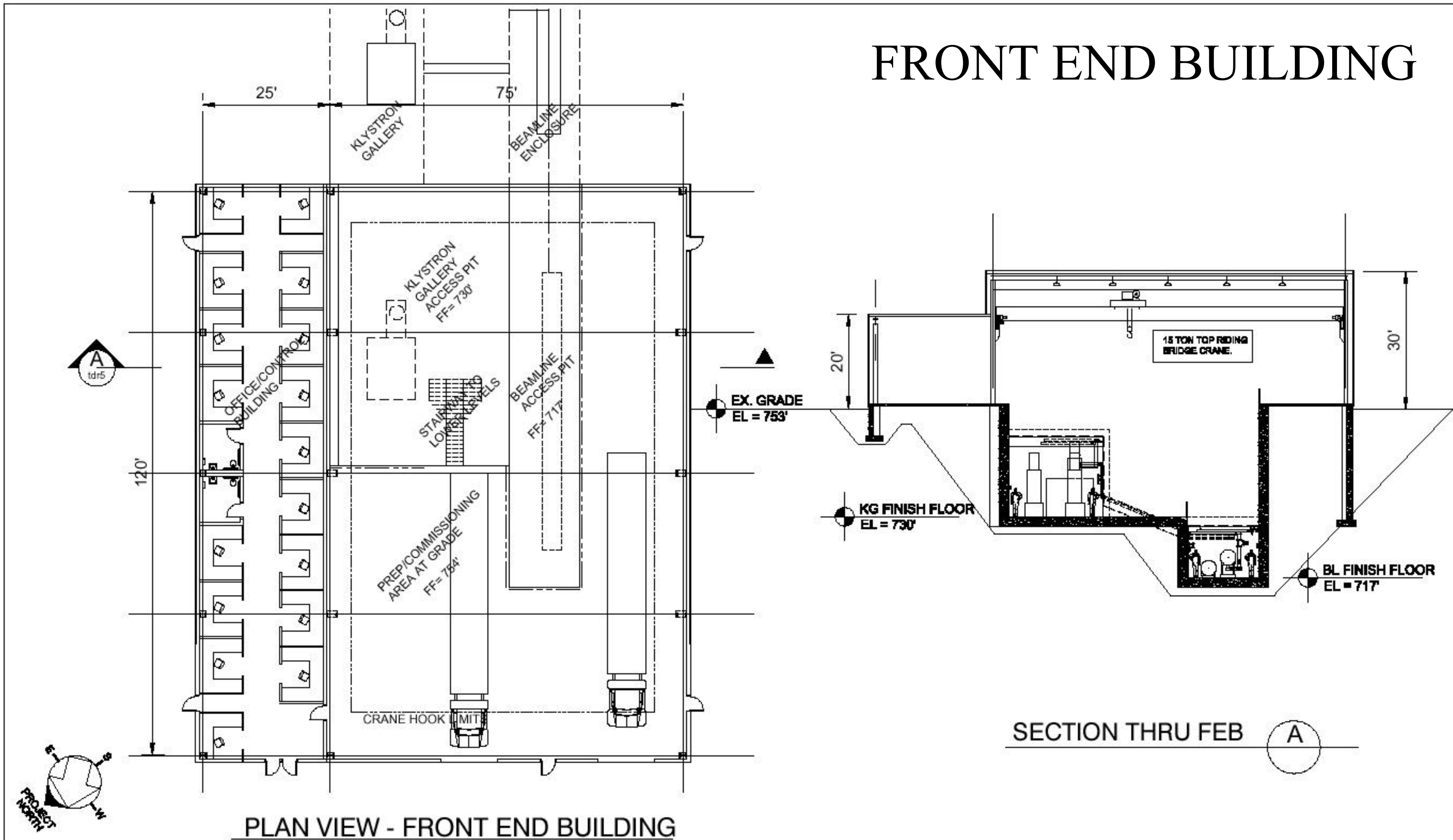
UNITED STATES DEPARTMENT OF ENERGY

8 GEV LINAC STUDY

CROSS SECTIONS

6-9-3 TDR-3

FRONT END BUILDING



REV.	DATE	DESCRIPTIONS		NAME	DATE
			DESIGNED		
			DRAWN		
			CHECKED		
			APPROVED		
		REVISIONS	SUBMITTED		

SCALE: 1" = 20'-0"

20 0 20 40
SCALE FEET

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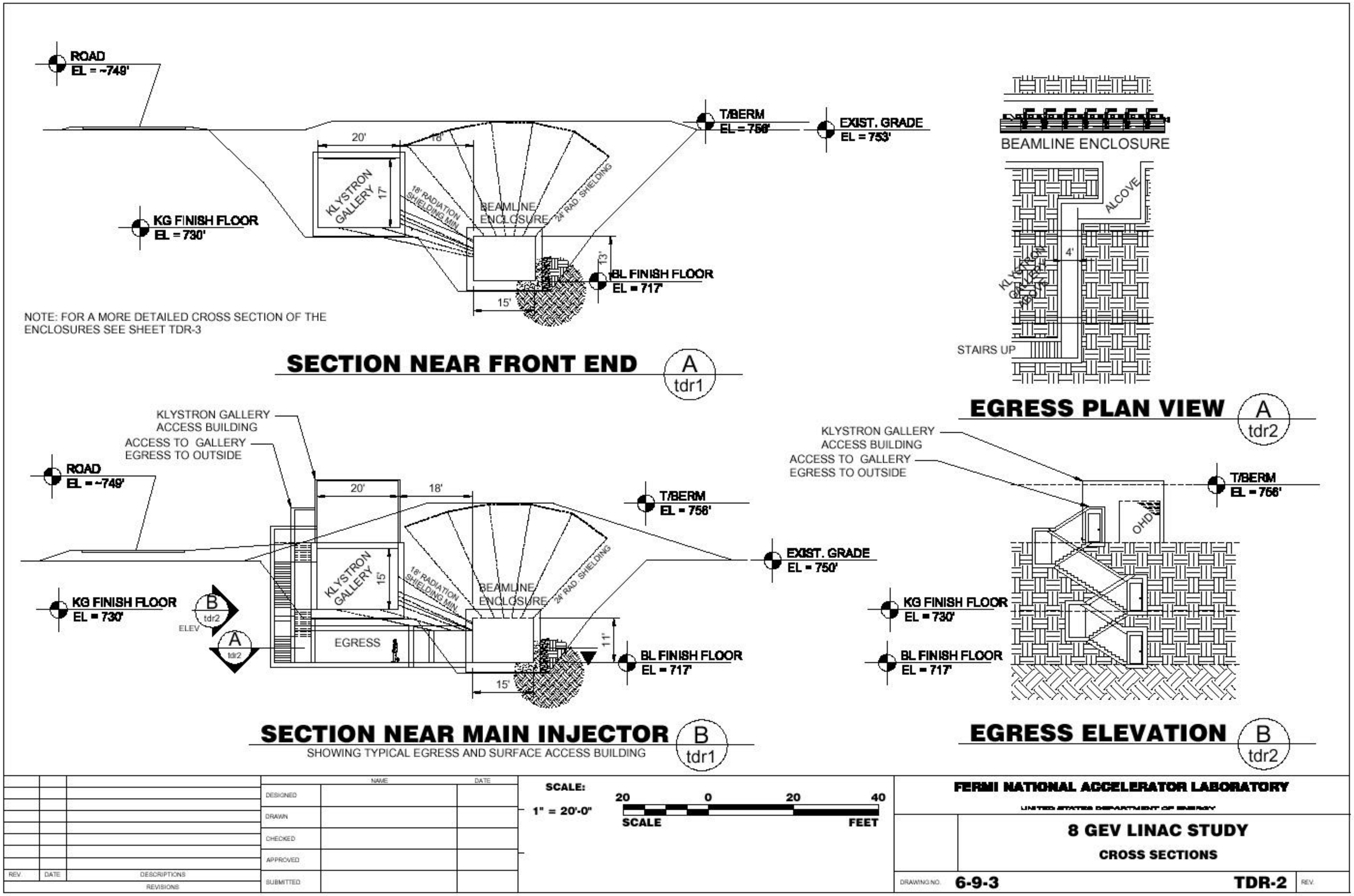
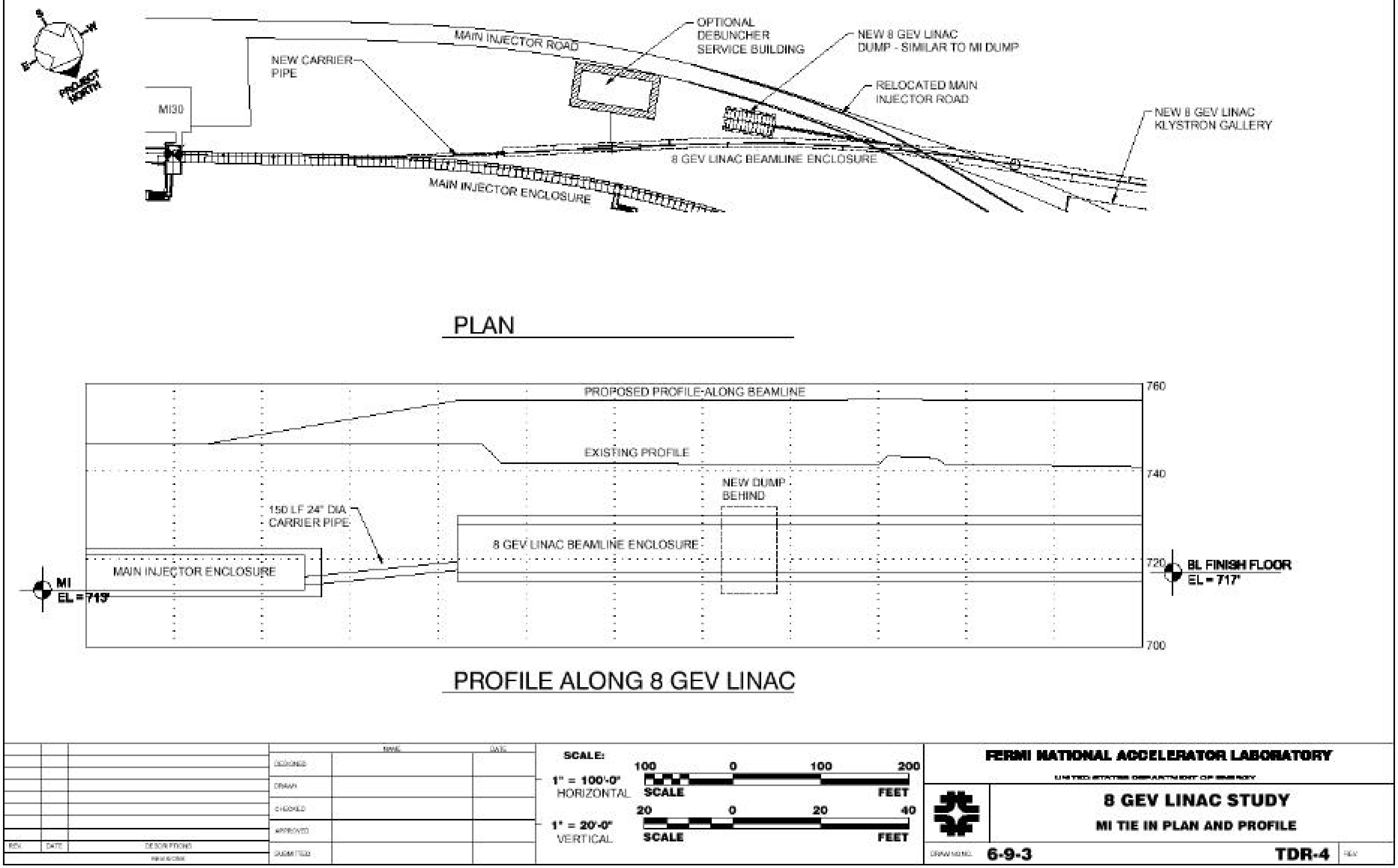
UNITED STATES DEPARTMENT OF ENERGY

8 GEV LINAC STUDY
FRONT END BUILDING

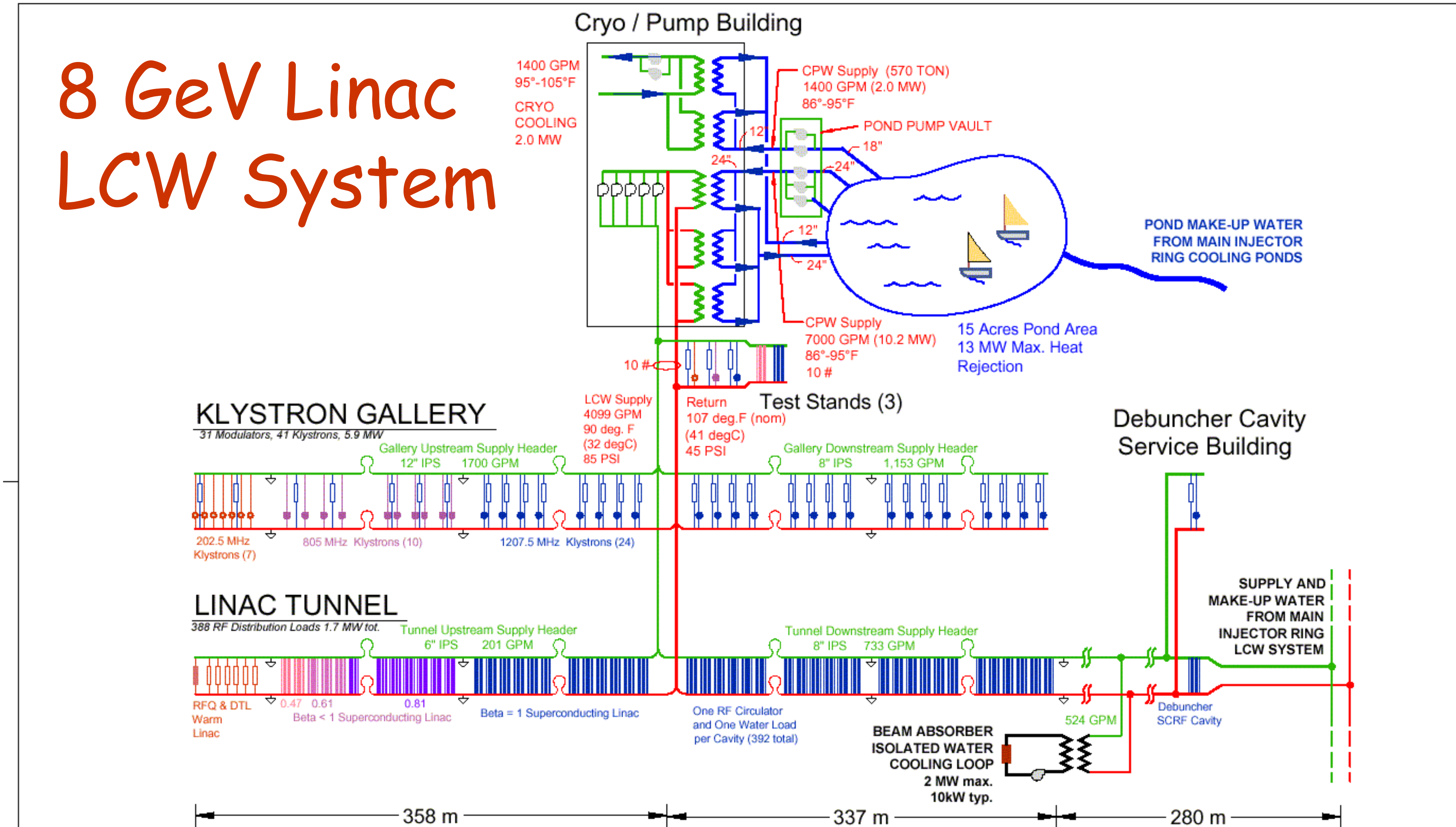
DRAWING NO. 6-9-3 TDR-5 REV.


ROAD
EL = ~749'
T/BERM
EL = 756'
EXIST. GRADE
EL = 753'
20'
18'
KLYSTRON GALLERY
17'
18' RADIATION SHIELDING MIN.
BEAMLINE ENCLOSURE
24' RAD. SHIELDING
KG FINISH FLOOR
EL = 730'
13'
BL FINISH FLOOR
EL = 717'
15'
NOTE: FOR A MORE DETAILED CROSS SECTION OF THE ENCLOSURES SEE SHEET TDR-3
SECTION NEAR FRONT END
A
tdr1
BEAMLINE ENCLOSURE
ALCOVE
4'
KLYSTRON GALLERY ABOVE
STAIRS UP
EGRESS PLAN VIEW
A
tdr2
KLYSTRON GALLERY ACCESS BUILDING
ACCESS TO GALLERY EGRESS TO OUTSIDE
ROAD
EL = ~749'
20'
18'
T/BERM
EL = 756'
EXIST. GRADE
EL = 750'
KLYSTRON GALLERY
15'
18' RADIATION SHIELDING MIN.
BEAMLINE ENCLOSURE
24' RAD. SHIELDING
KG FINISH FLOOR
EL = 730'
B
tdr2
ELEV
A
tdr2
EGRESS
11'
BL FINISH FLOOR
EL = 717'
15'
SECTION NEAR MAIN INJECTOR
SHOWING TYPICAL EGRESS AND SURFACE ACCESS BUILDING
B
tdr1
KLYSTRON GALLERY ACCESS BUILDING
ACCESS TO GALLERY EGRESS TO OUTSIDE
T/BERM
EL = 756'
OHD
KG FINISH FLOOR
EL = 730'
BL FINISH FLOOR
EL = 717'
EGRESS ELEVATION
B
tdr2
REV.
DATE
DESCRIPTIONS
REVISIONS
NAME
DATE
DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED
SCALE:
1" = 20'-0"
20
0
20
40
SCALE
FEET
FERMI NATIONAL ACCELERATOR LABORATORY
8 GEV LINAC STUDY
CROSS SECTIONS
DRAWING NO.
6-9-3
TDR-2
REV.

MAIN INJECTOR CONNECTION



8 GeV Linac LCW System



DESIGNED			SCALE: NONE
DRAWN	C. HOLMGREN	04-08-02	
CHECKED			
APPROVED			
SUBMITTED			

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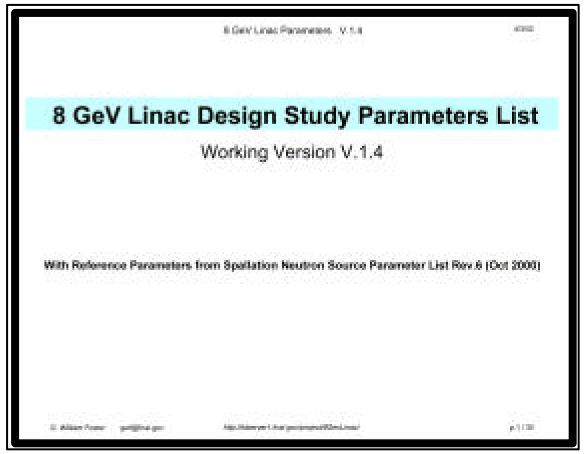
UNITED STATES DEPARTMENT OF ENERGY

8 GEV LINAC STUDY
LINAC POWER SUPPLY

DRAWING NO. 6-9-3 XX TDR-8 REV. XX

More Design Details



8 GeV Linac Parameters V.1.4

8 GeV Linac Design Study Parameters List

Working Version V.1.4

With Reference Parameters from Spallation Neutron Source Parameter List Rev.6 (Oct 2000)

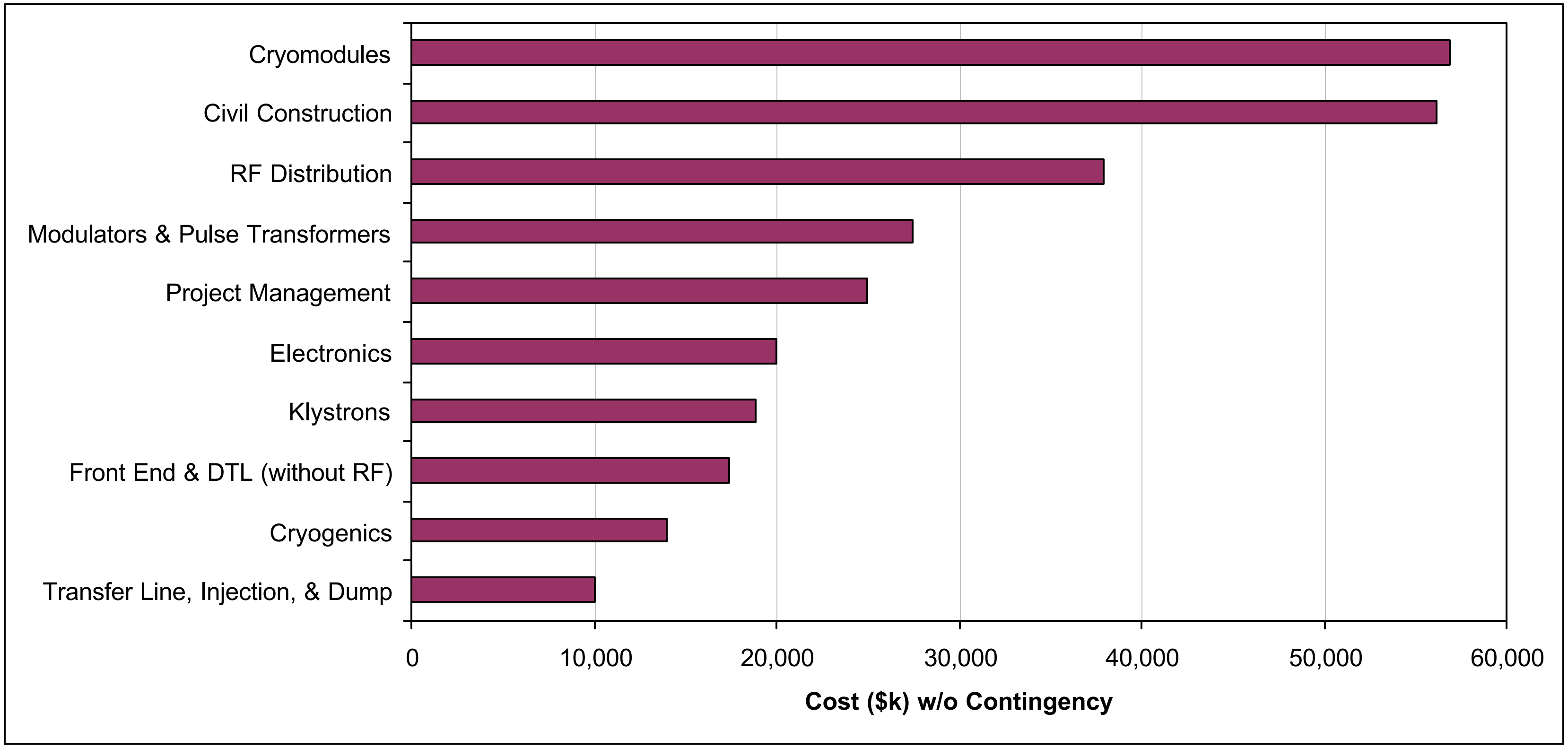
- Longer (technical) version of this Talk
- 30 Page Parameter List (v1.8)
- Cost Estimate Spread Sheet w/ BoE

http://tdserver1.fnal.gov/project/8GeVlinac

- Short Paper (Linac 2002) :

http://tdserver1.fnal.gov/project/8GeVlinac/Linac_2002

COST ESTIMATE (online)



$ 284 M + 30% Tax = $ 369 M

Staging and Cost Optimizations…?

- Build the new copper front end ASAP and get it off the budget. Useful for Synch. *or* Linac.
- Double the pulse width and cut the number of SCRF Klystrons and modulators by half. (10 Hz ==> 5 Hz?)
- Assume TESLA 800 surface fields will work:
  - Baseline 5 GeV linac by assuming TESLA 500 gradients,
  - Deliver 8 GeV linac by achieving TESLA 800 gradients.

384 Cavities ==> 240 cavities ;   Linac Length: 650m ==> 400m

Conclusions

- The 8 GeV SCRF Linac technically feasible with existing components & known costs.

  Exception: Fast Ferrite phase shifters need demonstration

- The SC Linac Option is somewhat more expensive than the synchrotron but has a number of advantages and possible secondary missions.